DRAFT
MATERIALS DIVISION

Virginia Department of Transportation

MEMORANDUM

GENERAL SUBJECT: Geotechnical Engineering		NUMBER: MD 246-05
SPECIFIC SUBJECT: CHAPTER 3 – Geotechnical Engineering		DATE: September 16, 2005
DIRECTED TO: District Administrators	SIGNATURE: Andrew Mergenmeier, PE *Signature on original copy of memorandum*	

Revise Chapter III by deleting all existing pages and replacing with the attached pages.

The Central Office Materials Division has significantly modified Chapter III of the Manual of Instructions (MOI). The attached version of Chapter III is to replace the version currently included in the MOI regarding instructions on how to conduct subsurface investigations for roadways and structures.

The main purpose of the revisions is to implement improvements to the quality assurance/quality control procedures that have been recently adopted by the Materials Division as it pertains to Preliminary Engineering studies. The following is a summary of the revisions:

- A new section defining the duties and responsibilities of the Materials Engineer during each of the milestones of the Concurrent Engineering Process.
- Guidelines and checklists for use in the preparation and review for various types of geotechnical investigations to improve the quality and accuracy of the reports.
- Outline of planning and investigation procedures in accordance with current accepted geotechnical engineering practices as defined in both FHWA and AASHTO publications.
- Adoption of the Unified Soil Classification System in accordance with ASTM D-2487 as the standard field and laboratory classification system for all geotechnical engineering studies. This method of classification is the most utilized in the industry and considered acceptable by both FHWA and AASHTO.

The changes noted above are included in Sections 301 through 307 in the attached version of Chapter III. As noted in the text of this Chapter there are several subsections that are currently under development. Accordingly, the attached version of Chapter III will be amended once these subsections have been developed. The remaining two sections of the Chapter, Sections 308 and 309, are essentially the same as the current version of Chapter III. These sections are also under review and will be amended at a later date. Also, other chapters of the MOI that make reference to the current Chapter III are under review.

This draft was originally sent out for review in March 2005. Comments were not received from all of those asked for their review. Upon receipt of the additional comments suggested revisions will be made.

Please direct your questions/comments to John Daoulas, P.E., (804.328.3141) or Stan Hite, P.E., (804.328.3108).

cy:

Commissioner
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Resident Engineers
District Materials Engineers
District Construction Engineers
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Virginia Dept. of Minority Business Enterprise
Virginia Ready-Mixed Concrete Association
Virginia Transportation Construction Alliance

Chapter III - GEOTECHNICAL ENGINEERING

SECTION 301 GENERAL

301.01 GENERAL

Geotechnics is defined as "the application of scientific methods and engineering principles to the acquisition, interpretation and use of knowledge of materials of the earth's crust to the solution of civil engineering problems. It embraces the fields of soil mechanics and rock mechanics and many of the engineering aspects of geology, geophysics, hydrology and related sciences." (Glossary of Geology, American Geological Institute, Washington, DC 1972.)

Within the Materials Division, the field of Geotechnical engineering for highway design, construction, and maintenance includes the activities of the District Geology/Geotechnical Section as well as the Central Office Geology and Geotechnical Engineering Sections.

The main objective of the geotechnical investigations is to acquire data needed for the design of roadways, embankments, cut and fill slopes, subgrade stabilization and/or ground improvements, retaining systems, and structure foundations.

Typically, the geotechnical investigation should accomplish the following:

(1) Locate and identify the various soil and/or rock types within the limits of the project.

(2) Locate and measure ground water levels within the limits of the project.

(3) Measure the capacity for the material to support loads (bearing capacity) at various depths beneath sites where structures and/or structural components will be located.

(4) Provide representative samples of each soil type or stratum for testing in the Soils Laboratory.

  (a) Obtain soil samples for testing to determine the particle size distribution, moisture content, Liquid Limit and Plastic Limit, etc.

  (b) Obtain undisturbed (Shelby tube) samples for testing to determine the rate of consolidation when load is applied, and to determine the shear (failure) strength of the soil under various load conditions.

(5) Obtain soil and water samples for tests to determine the potential for corrosion (pH and Resistivity).

(6) Identify geological constraints or conditions that may have an adverse effect on the project.

(7) Obtain samples of river bed/stream bed material for testing to assist in scour analysis when the proposed construction will involve streams and/or river crossings.

(8) Measure physical properties of soils using in-situ testing techniques in lieu of, or in addition to, sampling and laboratory testing.

301.02 TYPES OF INVESTIGATIONS

Primarily, geotechnical investigations are routine soil surveys and structure/foundation investigations that are performed during the preliminary engineering phase of a project. Occasionally, special geotechnical investigations are required in order to provide data for the solution of stability problems-landslides, fill failures, sink holes and embankment settlement, or to investigate claims alleging damage to private property. Vibration (seismic) investigations, ground water pollution studies, and water well damage investigations are examples of claim investigations.

This Manual pertains only to routine geotechnical investigations (soil surveys and the structure foundation investigations) that are ongoing functions of the Preliminary Engineering sections. Special investigations that are performed during the construction phase of a project, or for maintenance purposes, will not be covered.

301.03 GEOTECHNICAL REPORTS

A geotechnical report is a tool used to describe the site conditions and to provide design and construction recommendations to the roadway designer, bridge designer, and construction personnel. Site investigations have the objective of providing specific information on soils, rock, and ground water conditions. A Geotechnical Engineer and/or Geologist perform interpretation of the site investigation information. This information, combined with the results of laboratory tests and analysis, results in design and construction recommendations that are presented in a project geotechnical report. The information contained in the report is used as a reference during the design and construction phases of a project. Often, the geotechnical report is reviewed after the completion of the project (for resolving claims). Therefore, the report should be as clear, concise, and accurate as possible.

The geotechnical report content and format will vary by project type and size. However, all reports should contain basic essential information including: a summary of all subsurface exploration data; exploration logs and in situ test results; laboratory test results; ground water information; interpretation and analysis of the subsurface and laboratory data; specific engineering recommendations for design; discussion of conditions that may be encountered during construction (including recommendations for solutions for anticipated problems); and recommended plan notes and/or special provisions. Specific information for each type of report is included in Section 304 of this manual.

SECTION 302 GEOTECHNICAL DESIGN

302.01 GENERAL

THIS SECTION IS UNDER DEVELOPMENT. It will include aspects of project design, and consideration that should be made during analysis for:

Retaining walls

Sound walls

Use of geotextiles

Soil and Rock Slopes

Drilled shafts

Displacement piles

Spread footings

Shrink/Swell Factors

Signage and Light poles

302.02 FACTORS OF SAFETY

THIS SECTION IS UNDER DEVELOPMENT. It will include information on effective and economical design. Includes using appropriate factors of safety.

302.03 ESTIMATES FOR GEOTECHNICAL WORK

THIS SECTION IS UNDER DEVELOPMENT. It will include developing cost estimates for geotechnical work on projects.

SECTION 303 CONCURRENT ENGINEERING PROCESSES

303.01 CONCURRENT ENGINEERING MILESTONES AND RESPONSIBILITIES

VDOT has developed procedures for preliminary engineering project development. These procedures will contribute to quality assurance and quality control during the planning and implementation phases of construction and maintenance projects. If followed, these procedures will reduce the frequency and/or magnitudes of plan errors and will contribute to the desired result: to produce quality designed projects that are constructed on time and within budget.

The District and/or Central Office Materials preliminary engineering deliverables consist primarily of soil survey reports (that include pavement designs) and foundation reports. The Materials Division has developed QA/QC procedures that are to be followed during the development of these products described in Section 305 of this manual.

The Concurrent Engineering philosophy establishes guidelines for the involvement of all the contributors in the project lifecycle. The goals are to improve project coordination and communication, which will ultimately improve the quality of the design/construction process and product(s). Each preliminary engineering division has responsibility for producing high quality products in a timely and cost effective manner. For more detailed information on this process see the following link: http://virginiadot.org/projects/concureng-default.asp

Each project is developed around a sequence of events called milestones. These include: Pre-Scoping Meeting; Scoping Meeting; Preliminary Field Inspection (PFI) Meeting; Public Hearing Meeting; Field Inspection Meeting; and the Pre-Advertisement Conference/Constructability/Bidability Review Meeting.

Figure 3-1 is VDOT's Concurrent Engineering Process Flowchart. The following subsections describe the roles and responsibilities of the District Materials Section for each of the project milestones.

Concurrent Engineering Process Flowchart

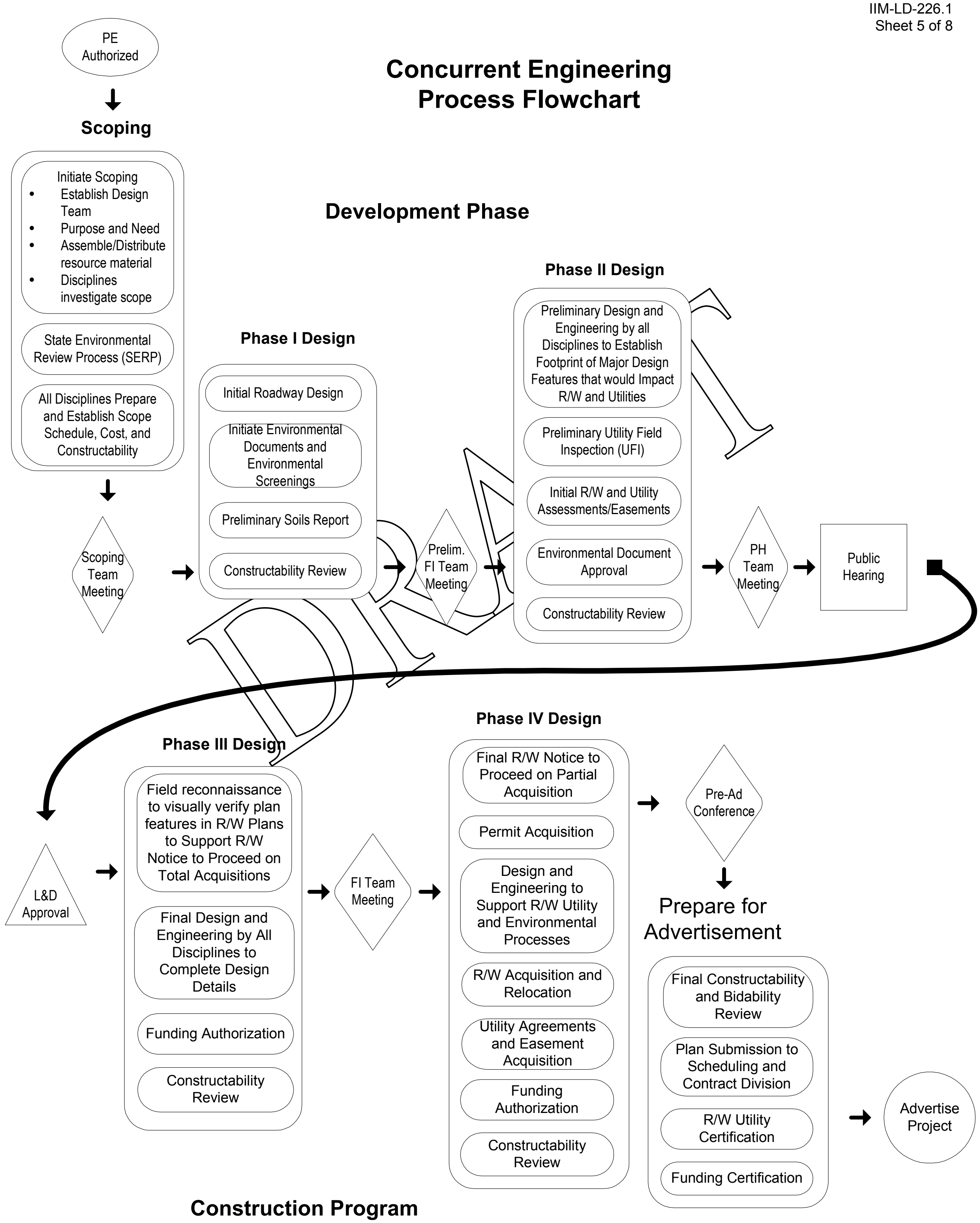

Figure 3-1 Concurrent Engineering Process Flowchart

303.01 (a) <u>Pre-Scoping Meeting</u>

Pre-scoping allows all project participants to begin to identify the elements of the project, establish an initial budget, and create the preliminary schedule for designing and developing the project. Purposes of pre-scoping include defining project elements, initiating and completing the SERP (State Environmental Review Process), and requesting traffic information.

Products resulting from the Pre-Scoping meeting include: preliminary project limits and types of improvements; preliminary project scope; preliminary project schedule (with major project tasks identified); preliminary project budget; and identification of project issues.

Project deliverables and responsibilities for Materials include reviewing historic data and maps, and performing field reconnaissance.

Project Team Responsibilities for Materials staff include providing input relating to project elements, schedule, budget, and constructability and design issues. See Figure 3-2.

303.01 (b) <u>Scoping Meeting</u>

Scoping allows all project participants to define the elements of the project including the budget and the schedule for designing and developing the project. Purposes of Scoping include defining and refining the preliminary project scope, confirming that the estimated advertisement date is attainable, and confirming that the initial construction cost estimate is accurate.

Products resulting from the Scoping meeting include project limits and types of improvements, project scope, project schedule with critical project tasks identified, project budget, and evaluation of all project threats and opportunities.

Project deliverables and responsibilities for the Materials Section include scope (in area of participation), schedule and budget information.

Project Team Responsibilities for the Materials Section include providing input relating to: schedule issues; PE, R/W, and construction costs; and assessment of materials related to project needs. See Figure 3-2.

303.01 (c) <u>Preliminary Field Inspection Meeting</u>

PFI allows managers/designers in various disciplines to review a preliminary set of roadway plans. It also serves as a review of the 'alignment and grade' and as a checkpoint for project progress. It is also a kick-off task point for major work to begin in Structures & Bridge, Mobility Management Engineering/ITS, Right of Way/Utilities, Environmental, and Materials.

Products resulting from the PFI meeting include: a review of the comments from the Value Engineering report; review and agreement on project alignment and grade; identification of items affecting cut/fill limits and earthwork; R/W/Utilities, permits, cultural resources, hazardous materials, and other environmental issues; the plan and schedule for completion of the deliverables necessary for the next project milestone; and soil/foundation investigation information for review at the public hearing.

Project deliverables and responsibilities for the Materials Section include the Preliminary Soil Report (when applicable). Also, input relating to initial roadway design, initial hydraulic analysis, and initial E&S (Erosion & Sediment) calculations, if requested.

Project Team Responsibilities for the Materials Section include developing the preliminary soils report which includes: preliminary slope design recommendations; preliminary pavement design recommendations; soils investigation (historical soil data) to support the public hearing presentation and subsequent soil survey reports; and foundation investigation (historical data) to support the public hearing presentation and subsequent major/minor foundation analyses and reports. See Figure 3-2.

303.01 (d) Public Hearing Meeting

The Public Hearing meeting allows managers/designers in different disciplines to review the design on a set of plans prior to the public hearing.

Products resulting from the Public Hearing meeting include: a general consensus relating to issues, documentation, and project details associated with supporting the public hearing; a plan and schedule for completing deliverables necessary for the next project milestone; initiating detailed design tasks after design approval is obtained; and a letter declaring local support.

Project deliverables and responsibilities for the Materials Section includes providing the subsurface investigation and laboratory data report used by the District or State Structure and Bridge Engineer or by the VDOT or Consultant Engineer responsible for the foundation analysis and preparation of the major structures report that is to be completed, and submitted, prior to the time of the Public Hearing Meeting as discussed in Section 304.04 of this Manual. Input relating to preliminary roadway design, preliminary hydraulic design, preliminary retaining structure design (standard and special), bridge hydraulic analysis, preliminary landscape design, preliminary sound barrier design, and environmental documentation is provided, if requested.

Project Team Responsibilities for the Materials Section include the subsurface investigation report for major structure foundations as described in Section 304.04 of this manual; and continuing to prepare the final soils report (including the final pavement section and slope recommendations). See Figure 3-2.

303.01 (e) Field Inspection Meeting

The Field Inspection meeting allows managers/designers in different disciplines to review a current set of plans for a project. It also allows for review and agreement on all concept plans and designs that might affect right of way. The major project effort after the field inspection is the acquisition of right of way, acquisition of permits, and the completion of final design activities.

Products resulting from the Field Inspection meeting are: a constructability review; evaluation of the scope, the schedule, and the construction estimate; and a plan and schedule for the completion of the deliverables necessary for the next project milestone.

Project deliverables and responsibilities for the Materials Section include the final soil survey report and the minor structures report. Input relating to roadway design, hydraulic design, retaining structure design, scour analysis, stream and/or wetland compensation/mitigation landscape design, hazardous materials assessment/mitigation, final environmental documentation, and structure or bridge design is provided, if requested.

Project Team Responsibilities for the Materials Section include the final soils survey report (which contains pavement section and slope recommendations) and the final minor structure foundation analysis and report. See Figure 3-2.

303.01 (f) Pre-Advertisement Conference/Constructability/Bidability Review Meeting

The CEI (Construction Engineering and Inspection) estimate is finalized at this stage, and the Project Manager will determine if the money necessary has been allotted in the 6-year plan to include adequate financial resources.

The Pre-Advertisement Conference (PAC) meeting allows managers/designers in different disciplines to review the final plans. This ensures that all disciplines are aware of current project information including schedule and budget. This review replaces the formal first submission of plans. At this point the plans are virtually complete and may only require minor adjustments to the quantities. Specifications are also complete at this point. Plans and bid documents are reviewed for completeness with regard to project scope, constructability, and bidability.

Products resulting from the PAC meeting are: completed plans; completed right of way agreements/deeds in hand; clear identification of any issues or open actions that may impact the submission of plans to the

Scheduling and Contract Division (and the subsequent advertisement date); and communication of environmental commitments.

Project deliverables and responsibilities for the Materials Section include input into final roadway design; streams/wetland mitigation/compensation; final landscape design; hazardous material assessment/mitigation; final design for retaining structures (special); and construction specifications, if requested.

Project Team Responsibilities for the Materials Section include providing input and support to the project team. See Figure 3-2.

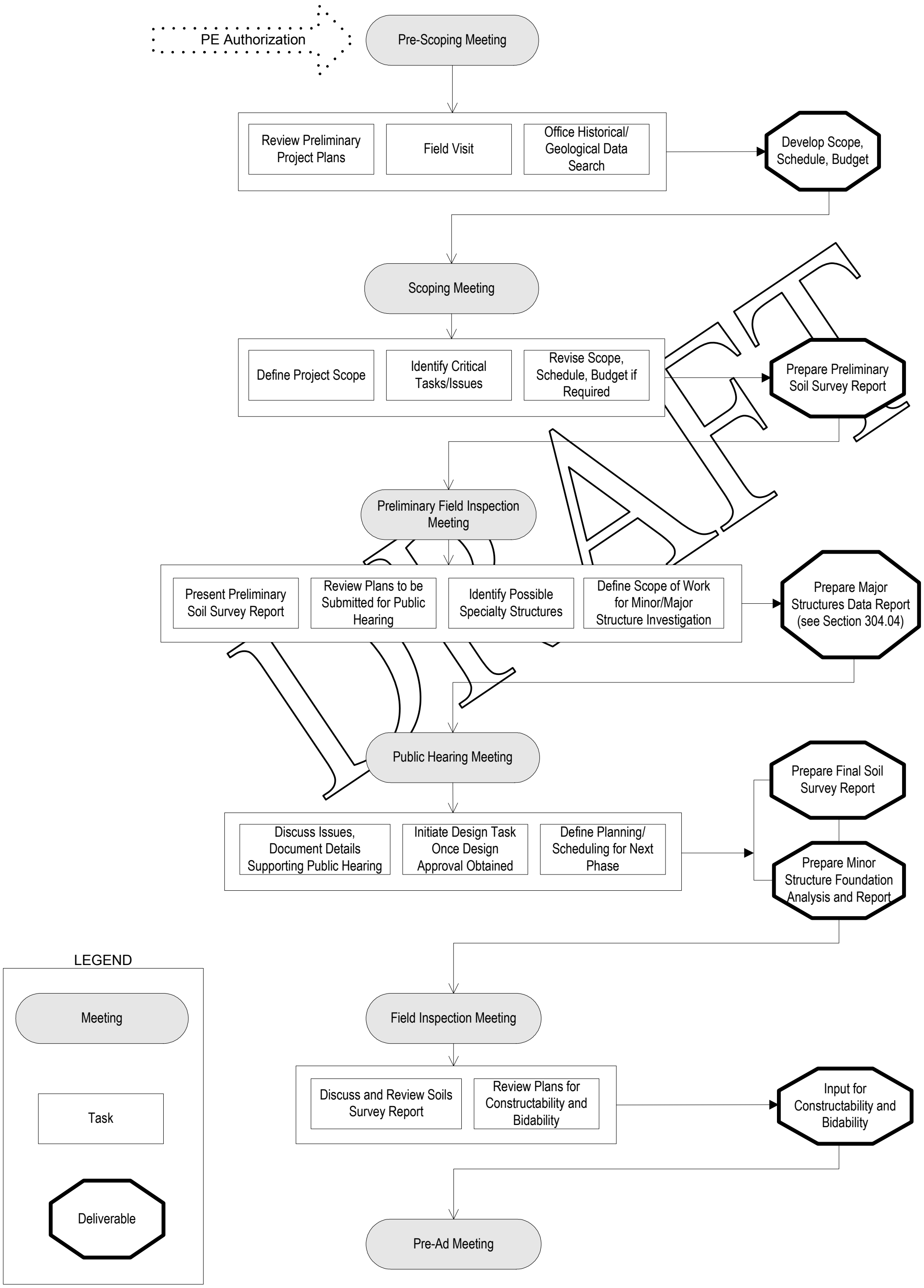

Figure 3-2 – District Materials Section Deliverables and Responsibilities Flowchart

SECTION 304 TYPES OF GEOTECHNICAL INVESTIGATIONS

304.01 PRELIMINARY SOIL SURVEY

304.01 (a) General

A preliminary soil survey should be performed during the initial phase of the project between the Scoping Meeting and the Preliminary Field Inspection Meeting [see Section 303 of this Manual]. The main purpose of the preliminary survey is to identify general site characteristics and subsurface conditions that should be considered during the planning and preliminary design phases of the project. The need and magnitude of this preliminary study will depend upon the size and complexity of the project. For most projects, the survey can be accomplished by performing a literature review in the office and a site reconnaissance in the field (as described in Section 306.02 of this Manual). If required, a preliminary subsurface exploration should consist of a minimal amount of borings. The purpose of the borings is to confirm the information obtained during the office reconnaissance, to investigate a specific area of the site (that could adversely effect the planning and design and/or construction of a project), and/or to provide physical data that can be used in preliminary design of foundations, pavements, stormwater management ponds, etc. The borings, if performed, should be drilled in locations that will allow their integration into the final subsurface investigation (that is performed during the final soil survey for the project).

304.01 (b) Preliminary Soil Survey Report

The preliminary soil survey should be completed, and the report submitted, prior to the time of the Preliminary Field Inspection Meeting. The report may be in the form of a memorandum or a formal report. The report should include a brief project description and a summary of the general site characteristics and subsurface conditions. It should also include preliminary engineering recommendations that should be considered during the planning and preliminary design of the project. It should be noted in the report that the information provided is for preliminary planning and design purposes only and may be subject to change once the final soil survey is performed. On some projects, such as intersection improvements, there may not be a need for a preliminary soil survey. If no preliminary soil survey is required, the final soil survey should be initiated. *A template for use in preparing a preliminary soil survey report is currently under development.*

This investigation is PPMS activity #34P.

304.02 FINAL SOIL SURVEY

304.02 (a) General

The final soil survey should be performed between the time of the Public Hearing Meeting and the Field Inspection Meeting. The final soil survey normally will not be completed until planning and design have progressed to the point where specific recommendations can be made for the geotechnical aspects of the work. This report generally addresses geotechnical recommendations used in the design of pavements, cut slopes and embankments. Also, construction considerations such as subgrade preparation, undercut, temporary dewatering, etc. should be addressed. Typically, geotechnical recommendations for pipes, culverts, stormwater management (SWM) basins, and retaining walls will be included in the Minor and Major Structures reports described in Sections 304.03 and 304.04, respectively. However, on small projects that have a limited number and size of pipes or culverts, SWM basins, or retaining walls of less than 10 ft high, it may be permissible to include recommendations for these structures as part of the final soil survey report. The Project Manager should be contacted first to determine if this manner of reporting would be acceptable for that particular project. If design and construction recommendations for Minor and/or Major Structures for a specific project are to be included in separate reports it should be noted as such in the final soil survey report.

The validity of the recommendations presented in the report will generally depend upon the quality of the factual data obtained for the particular project site. Factual data includes the subsurface investigation and soils laboratory test results. Discussions regarding formulation of a subsurface exploration and laboratory test program are included in Section 306 of this Manual. Other supporting data may include past experience, factual data previously obtained within the vicinity of the project site, document research, project information, site restrictions, etc. All supporting data used should be documented in the report. The FHWA checklists included on the Materials Division website **(*)** provides a guideline regarding the types of information that should be included in the final soil survey report.

(*) Go to FHWA website link to view checklist

304.02 (b) <u>Final Soil Survey Report</u>

The final soil survey should be completed, and the report submitted, prior to the time of the Field Inspection Meeting. The report is the means of communicating the site conditions, design recommendations and construction considerations to the Designer and Construction Engineer. The data and recommendations contained in the report usually are referred to continuously and for many different purposes during the design period, construction period, and frequently after completion of the project either to resolve claims or as information for future projects. The end users generally will include non-geotechnical engineers and/or personnel that have no engineering background at all. Therefore, it is essential the report be clear, concise, and accurate with little room for interpretation. The report should include a site description, proposed construction, summary of the subsurface exploration performed and the data obtained, summary of laboratory test results, recommendations for use in planning and design, and construction consideration/special provisions. *A template for use in preparing a final soil survey report is currently under development.*

This investigation is PPMS activity #34F.

304.03 MINOR STRUCTURES

304.03 (a) <u>General</u>

The minor structures investigation should be performed between the Preliminary Field Inspection Meeting and the Field Inspection Meeting. The minor structure report should provide geotechnical recommendations for the design and construction of stormwater management basins and for pipe and culvert foundations. In addition corrosion tests of both soils and water that can be used by the Location and Design Division to determine the type of pipe or culvert to be used in the design of the project. The preparation of a minor structures report should be the same as described in Section 304.02 for a final soil survey report. Guidelines that may be used to formulate a subsurface investigation program for minor structures are provided in Section 306.06 of this Manual.

Pipe and Culvert Foundations: At the request of the Location and Design Division, a foundation investigation will be performed for all pipes and/or culverts having diameters of 36" or greater. The subsurface conditions should be explored along the alignment of the pipe to at least one pipe diameter below the invert elevation of the pipe or culvert. The soil and water should be sampled and tested for pH and resistivity. Sources of water sampled include streams and/or groundwater. Approximately 11 pounds (5000 grams) of soil and 1 pint (500 milliliter) of water should be obtained for testing. Location and Design Division Memorandum IIM-LD-121.14 included on the L&D website provides specific criteria for use in the investigation and design of pipes and culverts. The Location and Design Division may request pH and resistivity testing prior to determining the type and size of pipes or culverts for a project. A foundation analysis may also be required for culverts or pipes that are less than 36" diameter if requested by the Designer. It is incumbent on the Geologist/Geotechnical Engineer to identify conditions that may impact the structural integrity of pipes and culverts regardless of size or if the Location and Design Division made a request. For example, culverts or pipes of less than 36 inches in diameter installed beneath embankments on soft ground could become severely damage due to settlement if the foundation beneath the pipe is not constructed adequately. A damaged pipe or culvert could lead to damage and/or failure of the embankment. Construction considerations relating to the installation of culverts and pipes due to high ground water and unstable soil conditions that may require sheeting and shoring and/or special dewatering techniques should also be addressed in the report regardless of the size of pipe and culvert to be installed. In addition, the soils that are to be excavated from within the pipe trench should be evaluated to determine the suitability of the material for reuse as compacted pipe backfill.

The structure locations will be marked on plans provided by the Location and Design Division. The plans should accompany the request submitted by the Location and Design Division.

Stormwater Management Basins*:* The following section addresses the need for soils investigations for stormwater management basins. The purpose of the basin is to protect the properties and waterways downstream from erosion due to increases in the volume, velocity, and peak flow of stormwater runoff. Unless otherwise noted on the project plans, it shall be assumed that all basins are designed as dry basins, with no permanently impounded water. The criteria that has been adopted by VDOT in the planning and design of a stromwater basin is outline in Location and Design Division Memorandum IIM-LD-195.5 included on the L&D website.

In conjunction with their request for the subsurface investigation for minor structures, the Location and Design Division shall provide the Materials Division with detailed plans outlining the proposed location and elevations of stormwater management (SWM) basin(s) as well as the size, location and type of outfall structure. The Hydraulic Engineer will typically request an investigation be performed. The Geologist/Geotechnical Engineer should formulate the subsurface exploration and laboratory test programs in order to determine if the native material will support the proposed dam and riser structure and not allow excessive seepage beneath the dam. In addition, to evaluate if the excavated material from within the basin is suitable for use to construct the proposed dam or for use as compacted structural fill for embankment construction in other areas of the project, if rock will be encountered in the area of excavation, and to determine if high ground water is present that could impact the performance of the SWM basin. Section 306.06 of this Manual provides guidelines that may be used to formulate of a subsurface exploration program for SWM basin(s).

If the height of the dam structure is greater than 15 feet or if the basin includes a permanent water pool, a complete engineering analysis and design of the dam structure is required. The dam should be designed as either a homogenous or zoned embankment along with adequate seepage controls such as a toe drain and a key trench. The type of embankment to be considered for design will depend in part on the material types available for use in construction of the embankment. The DCR (Department of Conservation and Recreation) SWM Handbook as well as the U.S. Department of the Interior Bureau of Reclamation publication entitled “Design of Small Dams” provides guidelines for design of dam structures. According to the L&D memorandum the dam should have a minimum crest width of 10 feet and upstream and downstream slopes no steeper than 3H:1V to facilitate both construction and maintenance.

Construction of stormwater facilities in areas that contains sinkholes is prohibited. Accordingly, special investigation and planning during the preliminary phase of the project may be required in areas of Karst terrain or areas where mining was previously performed. If SWM facilities are required along the periphery of a sinkhole or mine shaft, the design of such facilities shall comply with the guidelines in L&D Memorandum IIM-LD-228 (Sinkholes) and DCR Technical Bulletin #2 (Hydrologic Modeling and Design in Karst) and applicable sections of the DCR SWM Handbook. The Chief Transportation Geologist should be consulted and all data submitted for his review and comments.

This investigation is under PPMS activity #40.

304.03 (b) Minor Structures Report

The minor structures analysis and report should be completed, and submitted, prior to the Field Inspection Meeting. The same attention to detail discussed in Section 304.02 for a final soil survey report should be used to prepare the minor structures report. The report should include a site description, proposed construction, summary of the subsurface exploration performed and the data obtained, summary of laboratory test results, recommendations for use in planning and design, and construction consideration/special provisions. *A template for use in preparing a minor structures report is currently under development.*

This investigation is under PPMS activity #45 for culverts and under PPMS activity #40 for stormwater management basins.

304.04 MAJOR STRUCTURES

304.04 (a) General

Majors structures include all bridge piers and abutment walls; gravity or cantilever retaining walls greater than 10 feet high; MSE walls, tieback or soil nail walls, and sound walls of any height; and any structures to be supported on deep foundations (to include embankments). Typically, MSE walls and sound walls are presented as design/built items in the project bid documents. VDOT will generally only provide subsurface and laboratory test data for use by others in design of these structures. For sound walls, we may stipulate the type of foundation system that should be considered by the designer due to constructability issues. Also, provide soil parameters that should be used in design of the sound wall foundations that should be pre-approved by the Structure and Bridge Division's Geotechnical Engineering Section. The Project Manager or Designer should identify before the Scoping Meeting the major structures that are to be design/built and those designed in-house or out source to a design consultant. The Project Manager or Designer should submit a written request, usually in the form of a memorandum, when a major foundation structures study is required.

The major structures reports will be prepared by the either the State or District Structure and Bridge Engineer or by the VDOT or Consultant Engineer (Designer) responsible for design of the proposed structure(s). In most cases, it will be the responsibility of the State Structure and Bridge Division's Geotechnical Section to prepare this report. However, in some cases it may be the responsibility of a qualified member of the District Structure and Bridge Division or the Designer of the structure to perform this task depending of the type of structure. The written request that is required to initiate the performance of the major structure study should clearly state the party responsible for preparing the major structures report and how the data requested from the District Materials Engineer should be distributed.

In general, the major structures report will include geotechnical analysis and design recommendations of the structure(s) to include provisions that should be considered during construction of the structure(s). The Engineer preparing the major structures report should perform stability analysis beneath abutment walls, MSE walls and retaining walls unless otherwise requested by the Project Manager or Designer. The District Geologist/Geotechnical Engineer should perform stability analysis of all approach embankments directly beyond these structures as part of the final soil survey for the project. The responsibility of the District Geologist/Geotechnical Engineer during preparation of the major structures report includes the development and implementation of the subsurface exploration and laboratory test program and preparation of a data report for the proposed major structure(s). The data report should include a brief description of the subsurface and laboratory data presented as well as commentary on site characteristics that could impact the planning, design and construction of the structure(s). There should not be geotechnical analysis or design recommendations included in this report. The data report produced by the District Materials Division should be included as a supplement to the major structures report.

The FHWA checklists included on the Materials Division website **(*)** provides a guideline regarding the types of information that should be included in the geotechnical engineering report for major structures. Although the

District report only includes a portion of the information needed it is important to understand the significance this data has in the development of geotechnical recommendations for the structure(s).

There are a number of factors that can impact the formulation of a subsurface exploration and laboratory test program for use in developing geotechnical recommendations for design of a major structure foundation. These includes the type and size of structure, anticipated design loads, maximum settlement and lateral deflection criteria, site and subsurface characteristics, proposed project constraints, etc. Accordingly, the State and/or District Structure and Bridge Engineer and/or Design Engineer responsible for preparing the major structures report should be consulted during planning of the subsurface and laboratory test program prior to implementation. Guidelines that may be used to formulate a subsurface exploration and laboratory test program for major structures are included in Section 306 of this Manual.

(*) Go to FHWA website link to view checklist

304.04 (b) <u>Major Structures Report</u>

The same attention to detail discussed in Section 304.02 for a final soil survey report should be used to prepare the District Materials data report for major structures. The data report should provide a brief discussion of the proposed structure(s) and a summary of the subsurface exploration laboratory test program performed; a description of the site characteristics that existed at the time of the study; geology and subsurface soil and rock conditions to include a description of major soil and rock strata that exist beneath the site based upon interpretation of the subsurface exploration data and from literature review (if available); ground water conditions; and soil and rock properties as determined from laboratory and in-situ tests, if requested. *A template for use in preparing a District Materials data report for major structures is currently under development.*

This investigation is PPMS activity #41. Investigations for retaining walls and MSE walls are PPMS activity #54, and investigations for sound walls are PPMS activity #55. Minimum boring spacing and depths can be found in Table 3-1.

The major structures report should be completed, and submitted, prior to the Public Hearing Meeting. **The deadline for submission of the District Materials data report should be determined by the District or State Structure and Bridge Engineer or by the VDOT or Consultant Design Engineer responsible for preparing the major structures report prior to the time of the Scoping Meeting.**

<u>SECTION 305 QUALITY ASSURANCE/QUALITY CONTROL PROCEDURES</u>

305.01 <u>GENERAL</u>

This section contains procedures that should result in the accurate and timely preparation of soil surveys and foundation reports. The Geotechnical Program Manager will coordinate review processes for the Materials Division for internally or externally produced reports, except for major structure reports as noted herein.

FHWA have developed checklists for review of geotechnical engineering reports (GTR Checklists) and review of the geotechnical aspects of project plans, specifications and estimates (PS&E Checklists). The GTR checklists address important information that should be included in a typical project geotechnical report. The PS&E checklists covers important items to be checked to minimize possible errors and/or omission to geotechnical related information and design that should be included as part of the project plans, specification/notes and project estimate. The FHWA checklists can be found on the Materials Division website **(*).** Not all the information included on the FHWA checklists may be applicable to the different report types produce at VDOT. However, the checklists should still be used as a reference to assist in limiting errors and omissions in the preparation of reports and plan review of VDOT projects that are either prepared in-house or by an outside consultant. *The FHWA checklists are currently being tailored specifically for VDOT and will be included on the Materials Division website.*

(*) Go to the FHWA website link to view checklists

305.02 QA/QC FOR SOIL SURVEY REPORTS

The Quality Control for soil survey reports includes reviewing the boring logs, using FHWA checklists to assure completeness, and preparing the report using a standard templates *(currently under development)* discussed previously in Section 304 of this Manual.

The Central Office Materials Division will review the final soil survey report. This review is required for all interstate and primary projects, and involves reviewing technical accuracy and the adequacy of the investigation. Reports for secondary roadways can also be submitted and will be reviewed, if requested by the Districts. A flowchart for this process is shown in Figure 3-3.

The Central Office Materials staff under the supervision of the Geotechnical Program Manager will review the slope and undercut recommendations and, if needed, will conduct an independent slope stability analysis of critical slopes. The District's slope designs are usually based on experience and comparison with similar slopes of equal height and length in the area. The Central Office staff will assist in the design or provide a more detailed analysis if it is deemed necessary. The Central Office staff will also provide the design or analysis of any special slope treatment needed for stability. The Central Office staff will also review the recommendations offered for special treatment of stormwater basins and subgrade stabilization, and will modify as needed.

The Chief Transportation Geologist will review soil survey reports if there are special rock slope issues. Recommendations for rock slopes may require detailed analysis using techniques such as a Markland stereonet analysis. The Chief Transportation Geologist would also review impacts of highway structures on wetlands, ground water, or sinkholes.

The Pavement Design and Evaluation section will check the calculations in the pavement analysis, and will revise as needed. This would involve reviewing designs for pavement structures in new sections of roadway, overlays for existing pavements, and/or recommendations for remediation of existing pavement structures. Drainage issues that are related to the pavement are also addressed in this review. Before inclusion into the final plans, the Location & Design Division submits plan sheets (showing the pavement typical section) to the Pavement Design and Evaluation section for review.

For projects where the soil survey is prepared by a consultant, the review process is the same. All resulting review comments are sent the VDOT Project Manager.

305.03 QA/QC FOR MINOR STRUCTURE REPORTS

The District Geologist/Geotechnical Engineer prepares foundation investigations for minor structures. The report goes through the same review process as the soil survey QA process (see Figure 3-3). Review comments are sent to the VDOT Project Manager.

305.04 QA/QC FOR MAJOR STRUCTURE REPORTS

As discussed in Section 304.04 of this Manual, major structures reports are prepared by either the District or State Structure and Bridge Engineer or by the VDOT or Consultant Design Engineer responsible for design of the structure(s). The District Geologist/Geotechnical Engineer is responsible for the planning and implementation of the subsurface investigation and laboratory test program for use in preparation of the major structures report as well as preparation of a data report of their findings. To better assure that the information provided by the District Geologist/Geotechnical Engineer meets the needs of the project designers the review process should be performed in three phases as illustrated in the flowchart shown in Figure 3-4.

The first phase is to have the State and/or District Structure and Bridge Engineer and/or VDOT or Consultant Designer of the actual structure(s) and the Chief Transportation Geologist review the subsurface investigation and laboratory test programs and the schedule to complete these programs prior to implementation. This is to assure that the planned program will meet the needs of the Designer/Engineer responsible for preparation of the major structures report. Once approved, the District Geologist/Geotechnical Engineer will implement the approved program and prepare the data report. Upon completion of the data report, the District Geologist/Geotechnical Engineer submits a draft copy of the report along with the boring logs and laboratory test data to the Chief Transportation Geologist for review. During this second phase of review the Chief Transportation Geologist is to confirm that the report has been prepared in accordance with the approved program and to identify any unforeseen geologic conditions that may have an impact on the design and construction of the proposed structure(s) that may warrant further investigation. Once approved, the District Geologist/Geotechnical Engineer will forward a copy of the final data report to the State and/or District Structure and Bridge Engineer and/or VDOT or Consultant designer responsible for preparing the major structures report for their review and comments. If there are no revisions requested, the information included in the Districts data report will be incorporated as part of the major structures report. However, if additional subsurface investigation and testing is requested the Engineer responsible for preparing the major structures report should relay this request in writing directly to the District Geologist/Geotechnical Engineer. The written request should clearly state what additional information is needed and the reason for the modifications.

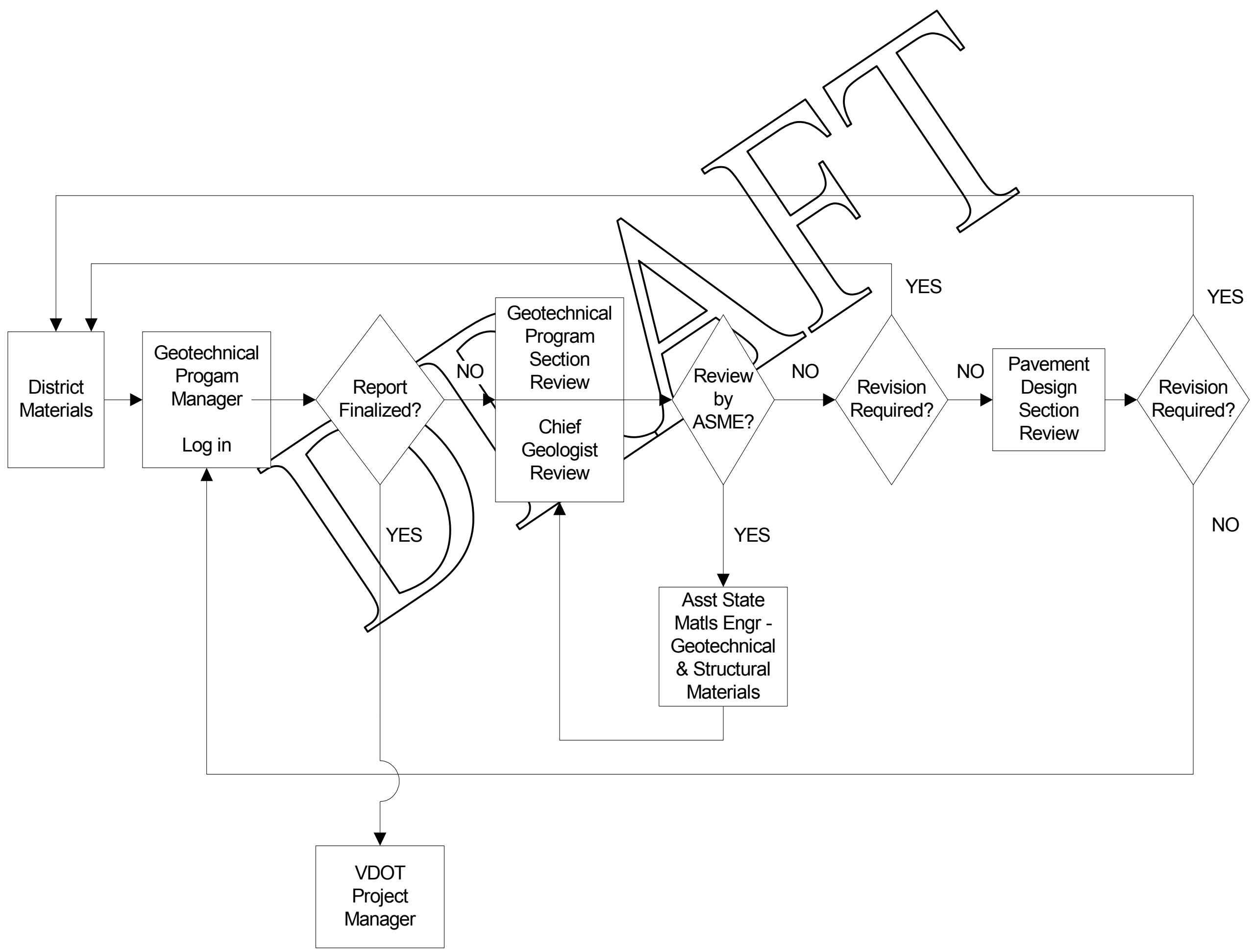

Figure 3-3 Soil Survey and Minor Structures Report QA/QC Review Flowchart

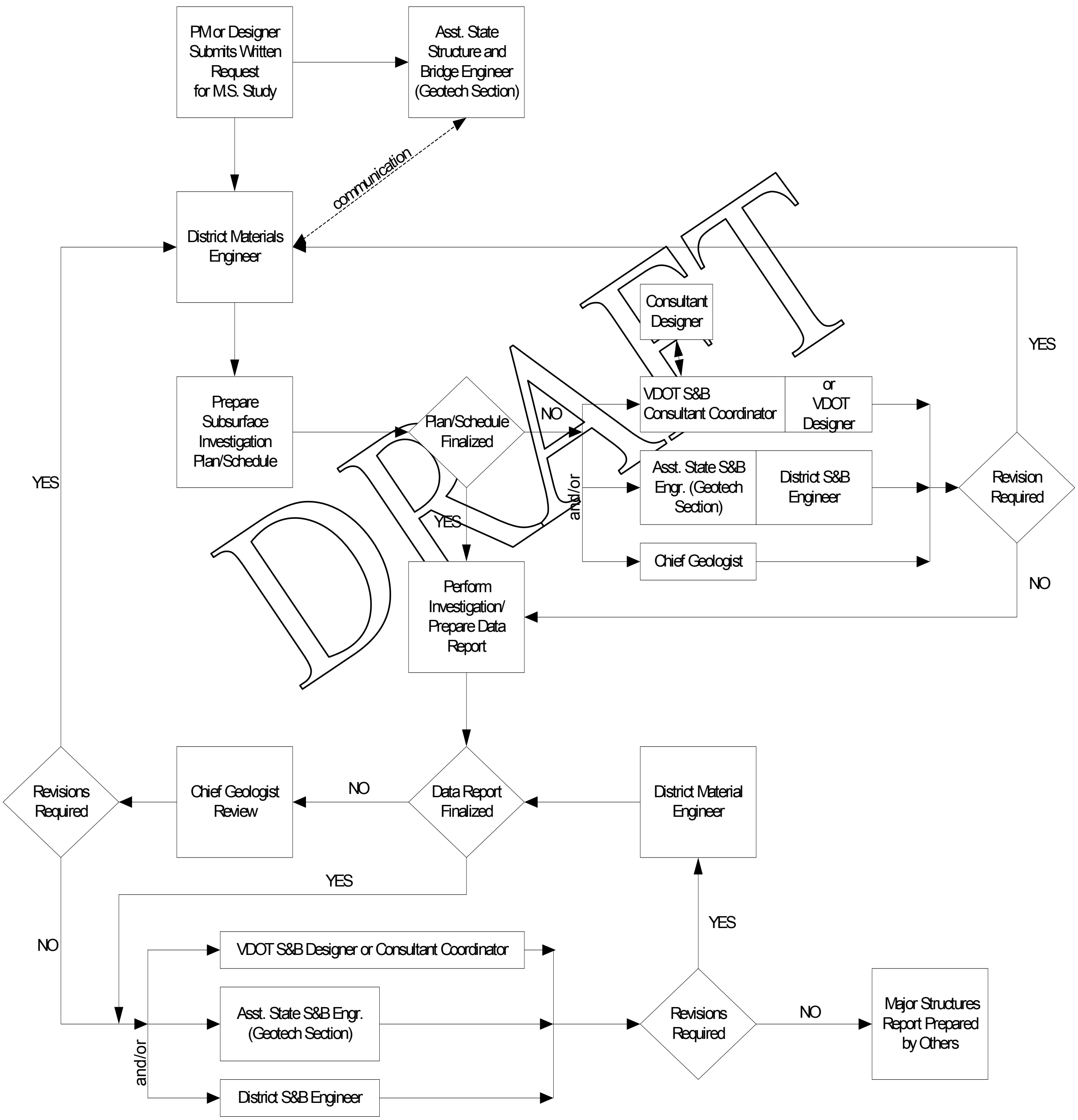

Figure 3-4 District Data Report for Major Structures QA/QC Review Flowchart

SECTION 306 PLANNING AND INVESTIGATION PROCEDURES

306.01 GENERAL

The District Materials Engineer shall assure the completion of a preliminary engineering investigation in the field and a review of literature pertaining to existing county, soil survey and/or geology maps showing potential problem soils. The District Materials Section drill crews will perform drilling, sampling and in-situ testing in the field unless an outside drilling consultant is contracted to perform this work. The District Geologist/Geotechnical Engineer for preliminary engineering work will be responsible for supervising and coordinating the work of the District drill crews. The level of supervision and coordination of the consultant driller will be determined by contract.

In situations that require the use of outside assistance, or the assistance of the staff at the Central Office Materials Laboratory at Elko, the District Materials Engineer will request such assistance through the Assistant State Materials Engineer responsible for Geotechnical Engineering and Structural Materials. Special investigations that originate outside the Materials Division shall be routed in a similar manner.

At least seventy-two hours prior to beginning any drilling, the District crew chief shall contact Miss Utility. If possible, the boring locations should be staked before scheduling the utility marking. No work should be performed until confirmation has been obtained from Miss Utility that all utilities have been cleared.

306.02 OFFICE AND FIELD RECONNAISSANCE

During the early stages of the project planning and development, the primary factors controlling cost and environmental acceptability of the project (from a Materials standpoint) are usually unknown. Reconnaissance is the first step to obtain physical data that can be used to develop the investigation and the design program. During this phase, the District Geologist/Geotechnical Engineer may be able to identify site characteristics that can adversely affect the design, cost and constructability of the project. The results of the reconnaissance may also provide sufficient information to allow suggesting alternate locations of structures, potential borrow areas, alignment changes to avoid adverse geologic conditions, etc. In addition, the data can be used to plan the soil survey (boring program) to meet the needs of the project while minimizing the time and cost required to perform the investigation. The level of effort during this phase will depend on many factors, including the schedule, size and complexity of the project, and prior experience from other projects. Two basic steps should be followed before mobilizing the drill rig to the site. The first step is to perform the Office Reconnaissance. During this step, the District Geologist/Geotechnical Engineer should collect and analyze available data related to the proposed project and project site. The second step is to perform the Field Reconnaissance. FHWA has developed a checklist of items to review during the office and field reconnaissance phases shown in Figure 3-5.

- ☐ Date
- ☐ Prepared by:
- ☐ Organization

- ☐ **ACCESSIBILITY**
  - ☐ Easy
  - ☐ By Vehicle only
  - ☐ Difficult by car - Walk only
  - ☐ Requires 4-wheeled drive
  - ☐ Dozer and Grading Required
  - ☐ Inaccessible
  - ☐ Details

- ☐ **VISIT TO SITE**
  - ☐ Date/Time of Day
  - ☐ Visitors
  - ☐ Weather Conditions
    - ☐ Sunny
    - ☐ Cloudy
    - ☐ Rain
    - ☐ Snow
    - ☐ Icy
    - ☐ Freezing
- ☐ **GROUND COVER**
  - ☐ Asphalt
  - ☐ Grass
  - ☐ Flowers
  - ☐ Bushes
  - ☐ Trees
  - ☐ Forest
  - ☐ Soil
  - ☐ Gravel
  - ☐ Concrete
  - ☐ Rock Outcroppings
  - ☐ Evidence of fill/debris
  - ☐ Prior Construction
  - ☐ Existing Buildings
  - ☐ Roadways
  - ☐ Other

- ☐ **EXISTING TERRAIN**
  - ☐ Level Ground
  - ☐ Sloping Conditions
  - ☐ Gentle Dip
  - ☐ Steep
  - ☐ Hummocky
  - ☐ Rolling Hills
  - ☐ Mountainous
  - ☐ Other remarks

- ☐ **SITE HYDROLOGY**
  - ☐ Dry - Barren
  - ☐ Desert
  - ☐ Surface Water Conditions
    - ☐ None
    - ☐ Swampy
    - ☐ Pond
    - ☐ Lake
    - ☐ Ocean
    - ☐ Stream
    - ☐ River
  - ☐ Subsurface Water
    - ☐ None
    - ☐ Not Obvious
    - ☐ Major Aquifer
    - ☐ Water Wells
    - ☐ Pumping from deep wells
    - ☐ Other Details

- ☐ **SITE DRAINAGE**
  - ☐ Runoff Features
    - ☐ Erosion
    - ☐ Ponding
    - ☐ Waterfalls
    - ☐ Piping
    - ☐ Swale
    - ☐ Other
  - ☐ Natural
    - ☐ Excellent
    - ☐ Good
    - ☐ Fair
    - ☐ Poor
  - ☐ Artificial Drains
    - ☐ Stormwater System
    - ☐ Retention Pond
    - ☐ Vertical wick drains
    - ☐ Pumping Stations
    - ☐ Other

- ☐ **SOIL AND ROCK CONDITIONS**
  - ☐ Surface Soils
    - ☐ Topsoil
    - ☐ Presence of Fills
    - ☐ Evidence of Debris
    - ☐ Pollutants/Contaminants
    - ☐ Agrarian types/farming
    - ☐ Evidence of slope instability
      - ☐ Landslides/slips
    - ☐ Creep
    - ☐ Cracking
    - ☐ Scour
    - ☐ Heave
    - ☐ Subsidence
  - ☐ Cut/Quarry Operations
  - ☐ Fill/Borrow
  - ☐ Other

- ☐ Subsurface Soils
  - ☐ USCS soil types:
    - ☐ GM, GC, GP, GW
    - ☐ SM, SC, SP, SW
    - ☐ CL, CH, ML, MH
    - ☐ Pt, OL, OH
    - ☐ Other

  - ☐ Surface Rocks
    - ☐ Loose cobbles
    - ☐ Boulders
    - ☐ Rock outcroppings
  - ☐ Type of rocks
    - ☐ Igneous
    - ☐ Sedimentary
    - ☐ Metamorphic
    - ☐ Details
  - ☐ Rock Features
    - ☐ Jointing Patterns
    - ☐ Faults
    - ☐ Discontinuities
    - ☐ Weathering
    - ☐ Planes of weakness
    - ☐ Evidence of talus
    - ☐ Karst/sinkholes
    - ☐ Caves
    - ☐ Other

- ☐ **INVESTIGATIVE OPERATIONS**
  - ☐ Existing test pits
  - ☐ Existing boreholes
  - ☐ Cased holes
  - ☐ Blasting operations
    - ☐ Dynamite
    - ☐ ANFO
    - ☐ Rippers
    - ☐ Percussive Drills
  - ☐ Erratics/ boulders
    - ☐ Coreholes
    - ☐ Diamond drilling
    - ☐ Wireline drilling
  - ☐ Exploratory Adits
    - ☐ Vertical shafts
    - ☐ Tunnels
    - ☐ Pilot Holes

Other info:

- ☐ **PRIOR INFORMATION**
  - ☐ Tax map records
    - ☐ Federal Documents
    - ☐ State records
    - ☐ County tax maps
    - ☐ City records files
    - ☐ Personal files
    - ☐ Interviews with neighbors and nearby businesses:

  - ☐ **TOPOGRAPHIC DATA**
  - ☐ USGS Quadrangle Maps
  - ☐ State Survey
  - ☐ County Surveys
  - ☐ Site Survey
    - ☐ Transit/Level
    - ☐ Aerial Photos
    - ☐ GPS data
  - ☐ Details
  - ☐ **GEOLOGIC INFORMATION**
    - ☐ USGS Geologic Maps
    - ☐ State Geologic Surveys
    - ☐ Field Mapping by geologists
    - ☐ Specimens for lab analysis
    - ☐ Details on geologic setting

- ☐ **UTILITIES**
  - ☐ Existing overhead lines
  - ☐ Marked gas lines
  - ☐ Easements
  - ☐ Manholes
  - ☐ Sewer outfalls
  - ☐ Power substations
  - ☐ Electromagnetic readings
    - ☐ Ground penetrating radar, VEM surveys
    - ☐ Magnatometer
    - ☐ Resistivity measurements
  - ☐ Other

- ☐ NOTES & REMARKS

Figure Checklist items for site reconnaissance

<u>Figure 3-5 Checklist for Planning and Reconnaissance</u>

Office Reconnaissance

Office Reconnaissance is generally a "Literature Research" to accumulate existing information on a particular project location before performing the field investigation. This includes a detailed review and understanding of the preliminary plans. Items of interest include types of structures and anticipated design loads, road alignments and anticipated cut and fill grades, locations and depths of utilities or other underground infrastructure, storm water management facilities, right-of –way and environmental restrictions, etc. These items may affect the planning and implementation of the field investigation and the laboratory testing program. Existing literature may consist of reports, journals, geophysical logs and maps, or non-printed data such as aerial photographs or personal communication with individuals having local knowledge. Some common literature sources may include:

Topographic Maps	Assessment of landforms such as slopes, sinkholes, outcrops and stream crossings, and their characteristics such as degree of planarity or convexity/concavity and contour irregularity, can assist in the interpretation of subsurface conditions and materials.

Geological Maps	The most important detail to be obtained from a geologic map is the particular formation(s) that may exist at the site. Using experience and available information, certain soil characteristics (that can be utilized in design) can be deduced from, and associated with, various soil and rock formations. The most common reference maps are the U.S. Geological Survey (USGS) quadrangle maps. These maps, and other geologic publications, can be obtained from the VA Department of Mines, Minerals and Energy (Division of Mineral Resources).
Agricultural Maps	Soil Survey Maps, produced by the U.S. Department of Agriculture (USDA), can provide a general guide as to the soil and rock types that may be present at relatively shallow depths beneath the project site.
Aerial Photographs	Aerial photos provide an overview of the site. The photos can provide general information on topography, vegetation, access, etc., for a particular area. The photos show the actual site conditions at a specific moment in time. Comparison of photos taken at different times may reveal changes in terrain and surface features. The causes of the changes may not be apparent at the time of the study, but may become apparent and costly at the time of construction. Examples include ravines that have been filled and previous building locations.
Existing Soil Surveys/Borings	Borings from previous investigations can be utilized to estimate the subsurface and ground water conditions that can be expected. The materials and conditions previously encountered can provide invaluable information for the initial planning of the project field investigation.

There are other resources that may be useful in evaluating the site and soil characteristics. These include well drilling logs, historical reports/maps, journals, research studies, etc. Obviously, the extent of the office research should be determined considering the scope of the project and the ease of acquiring the historical information.

Hazardous Materials - During the office reconnaissance phase of the project, particular attention should be given to past and/or present sources of potential generators of hazardous waste. As an example, an old structure that no longer exists may have been a fueling station where underground storage tanks may still exist. Leakage from tanks may have occurred, resulting in soil and ground water contamination. Other possible sources of contamination include areas of uncontrolled fill or landfills, trash piles, chemical producers or users located up gradient of the project site, etc. It should be standard practice to contact the District Environmental Manager to confirm the absence or presence of potential sources of hazardous materials or pollutants in the vicinity of the project site.

If, during the progress of the boring, the drill should puncture pipes, drums, or tanks, or sever wires or cables, drilling should be suspended immediately, the drilling tools should be left in the borehole, and the area around the drill cleared of bystanders and other persons. The District Materials Engineer and appropriate utilities company(ies), Department of Environmental Quality, or Hazardous Response Team should immediately be notified and given all the details relating to the incident.

Wetlands – During the office and field reconnaissance, crews should look for potential wetland areas within the project limits. If wetlands are detected, the District Environmental Manager should be notified. Crews should also coordinate with the District Environmental Manager to locate wetland sites before moving equipment into the area.

Field Reconnaissance

After the office reconnaissance has been completed and a general boring layout determined, the District Geologist/Geotechnical Engineer should visit the site. Whenever possible, the driller should accompany the Geologist/Geotechnical Engineer. The main purpose of the visit is to view the site and record any facts that may affect the design and construction of the planned project or the proposed field investigation. Additionally, the visit will provide information pertaining to site access, confirmation of the boring layout, special equipment needs, etc. Several key factors that should be considered during field reconnaissance are listed in the AASHTO Manual of Subsurface Investigations. These include, but are not limited to, borehole accessibility, boring layout, existing structures and utilities, surface anomalies, vegetation, rock outcrops and exposed soil cuts, surface and subsurface water, wetlands, existing slopes and gullies, areas of existing fill, geologic constraints, and environmental considerations. The key factors that should be considered will depend on the geographic setting, size and complexity of the project, geologic conditions, etc., that will be identified during the office reconnaissance. On large projects it may be impractical to traverse the entire site. Accordingly, the office reconnaissance should be used to maximize the effectiveness of the field investigation. The field reconnaissance will identify the areas of the site that contain materials and/or conditions that pose the greatest risk to the success of the project in both the design and construction phases. It is important that written documentation of the observations be included in the project file. This will provide evidence of the site conditions that existed at the time of the investigation. An example of a field reconnaissance checklist is included in Figure 3-5. This form may be modified to meet the specific needs of the project, geographic setting, area geology, etc. On very small projects or projects under a strict time line, the field reconnaissance may be combined with the drilling operations. However, under normal circumstances, the field reconnaissance should be performed before sending the drill crew to the site.

306.03 PERMISSION TO ENTER PROPERTY

No investigation is to be undertaken on any property that is not within the highway right-of-way unless permission is obtained from the property owner or from the person having authority to grant such permission. This restriction includes crossing of property by personnel and equipment to gain access to another property where an investigation is to be conducted. Property belonging to other government bodies, agencies, or institutions, and highway property that is not part of the public road system, are also included in this restriction.

The District Geologist/Geotechnical Engineer, or other person in charge of the investigation, is to ascertain that all property owners have been notified and that permission to access to the property for the purpose of conducting the investigation has been granted. This is to occur before the commencement of any work. The property owner should be advised of the nature and extent of the investigation. They should also be provided with the name and telephone number of the person to be notified, usually the District Materials Engineer, in case problems or additional questions arise. Any legitimate questions that cannot be answered by the Geologist/Geotechnical Engineer or other person in charge should be referred to the District Materials Engineer. The property owner should receive a prompt response. This need not interfere with the commencement of the investigation, unless permission to enter is denied.

The owners should be advised that a follow-up inspection by the District Materials Section approximately 30 days after the initial survey. The purpose of the inspection is to check for subsidence of the backfill in the boreholes. In all cases when property has been damaged or is likely to be damaged by the drill crew and/or equipment, the person in charge of the crew should attempt to contact the property owner and explain that a Department representative will be in contact to make restitution for the damage. The Right-of-Way and Utilities Division will handle appraisals of the amount of damage and they will make arrangements for the actual payment of the assessed value of the property that was damaged. At the discretion of the

Geologist/Geotechnical Engineer, it might be advisable to photograph the property before commencing fieldwork.

In any case where the property owner refuses to grant permission to make the necessary exploration, the Geologist/Geotechnical Engineer is to avoid an argument. The Geologist/Geotechnical Engineer will immediately request that the District Materials Engineer visit the property owner in an effort to secure permission. If the District Materials Engineer is unsuccessful in securing the permission, the DME should seek the advice and/or direct assistance from a representative of the ROW and Utilities Section to resolve this matter.

306.04 RAILROAD PROPERTY

A working arrangement has been established with the railroad companies in Virginia through the Department of Rail and Public Transportation whenever a project requires entry on or accessing through railroad property. To perform work on or accessing through railroad property, the District Geologist/Geotechnical Engineer is to write to the Department of Rail and Public Transportation Division (DRPT) and request that arrangements be made for permission to enter. A copy of the letter should be sent to the office of the Assistant Administrative Services Officer, (who will arrange for the insurance). Two (2) copies of the situation plans (showing the locations of the borings) are to be forwarded with the letter of request. The letter of request , shall include the following information:

(1) Name of the railroad.

(2) Lateral limits of the job (with respect to the nearest railroad milepost) and the locations of abutments and/or piers relative to the tracks.

(3) Project Number.

(4) Special requirements such as, flagperson, train schedule, etc.

(5) Estimated date drilling will start.

(6) Estimated date drilling will end.

The Department of Rail and Public Transportation and the Assistant Administrative Services Officer must be notified if a time extension is required.

The DRPT may request the estimated cost of all drilling operations performed on the railroad right-of-way, and the type of equipment to be used.

For investigations performed by Consultants, the Department will secure the right of entry and a list of any restrictions. The Department will either secure or reimburse the Consultants for obtaining Railroad Protective Liability Insurance coverage for the Consultant when borings are required on railroad property.

306.05 STAKING THE BORINGS

The proposed center line/base line (or boring locations) should be marked before an investigation is started. This is the responsibility of the District Survey Party Supervisor. The Project Manager should notify the District Materials Engineer promptly in the event of an alignment change. On some projects the District Geologist/Geotechnical Engineer may elect to use existing structures that are shown on the project site plans as a reference to locate the borings during the boring stakeout. The method used to stakeout the borings and used to determine the ground surface elevations at the boring locations should be noted in the reports submitted by the District. Elevations may be determined by the District Surveyor, obtained from the project plans, or referenced to a benchmark established in the field. If a benchmark is used the type, location and elevation of the benchmark should be described in the report.

306.06 FORMULATION OF THE SUBSURFACE INVESTIGATION PROGRAM

The most difficult and critical part of the planning phase of a project involves the decisions regarding sampling/investigation methods. The planning for the exploration should assure an adequate number of borings, proper locations and depths of borings, and sufficient laboratory tests to produce data required for a thorough analysis. The exploration should result in recommendations for cost-effective geotechnical design and construction, and a reduction in issues that would cause claims. The development of the subsurface program cannot be reduced to simple guidelines that fit all site conditions. Each project must be evaluated according to its specific site characteristics, types of proposed facilities, and the amount of funds available. However, the following guidelines should be considered in order to develop an adequate subsurface investigation program.

Various sampling methods and types of field investigation equipment are available for use in conducting an effective subsurface exploration program. Some of the more common sampling methods and equipment types available to VDOT are discussed in Section 309 of this Manual. Hollow-stem auger drilling, in conjunction with performing Standard Penetration Tests (SPT), is generally the most practical and economical method of field investigation currently being utilized by VDOT. Therefore, the guidelines included herein assume that the subsurface investigation program will be developed utilizing this type of investigation equipment. The SPT data will generally provide the necessary data for soils needed in the development of recommendations for use in the design and construction of pavement subgrades, roadway embankments and foundations.

Auger probe borings (soils described and sampled using auger cuttings without the performance of any in-situ testing) does not provide qualitative data that can be used to evaluate the in-situ strength and constructability characteristics of soils. Therefore, the use of auger probe borings should only be used for projects that are based on past experience of the strength and constructability characteristics of the soils are not expected to adversely affect the design and construction of the project or supported by in-situ data previously obtained at the project site. Auger probe borings may be applicable for projects such as intersection improvements, bulk sampling of material for laboratory testing such as Proctor and CBR tests, or the evaluation and sampling of potential borrow sources. Auger probe borings are not acceptable when evaluating critical structures such as deep cuts, high fills, and any major structures. **Commentary of the assumptions and/or experience used to develop the recommendations and/or conclusions should always be included in the report.**

The required number, spacing, location and depth of borings should be determined by taking account specific needs based on proposed structures, load conditions, design parameters, access issues, geologic constraints, and expected stratigraphy and ground water conditions. Table 3-1 provides minimum guidelines for the number, spacing and depth of borings. Boring location and spacing guidelines are also illustrated in Figures 3-6a, 3-6b, 3-7a and 3-7b. These guidelines should be considered when developing the subsurface investigation program for structures included on most VDOT projects. These guidelines were developed based on recommendations included in the AASHTO, FHWA, and NAVFAC DM-7 manuals, and should be used as a first step in developing the exploration for a project. The actual boring layout and depth will depend on the specific needs and type of the project, site access, site and geologic conditions, existing site and subsurface information, and experience.

Typically, the soils should be sampled continuously within the upper 10 feet of the ground surface and at 5-foot intervals thereafter. However, in areas underlain by varied soil deposits and/or rock formations, it may be necessary to adjust the sampling intervals to capture the breaks between the soil and/or rock types, and to assess consistency across the site. For example, continuous sampling below 10 feet may be desirable in order to define the depth of deep existing fill soils or unsuitable natural soils. These types of materials could influence the planning, design and cost of a project. A Standard Penetration Test should be performed at each of the sampling intervals. The SPT data, along with the results of the moisture and classification tests can be used to estimate (through published correlations of similar soils) the strength and compressibility characteristics of soil for use in design. However, the adequacy of the estimated values will depend on the type of proposed structure and the geological conditions. At least one Shelby tube sample should be obtained for each cohesive soil stratum having strength and compressibility characteristics that cannot be adequately estimated. For these soils, laboratory tests will be required. Undisturbed samples may not be needed in each boring if the soil deposits throughout the site are relatively homogeneous. For projects requiring CBR and proctor tests for use in pavement and embankment design, a minimum of 50 pounds of soil should be obtained from the desired stratum. Test each type of soil being considered for pavement support and/or use as compacted fill.

A geophysical survey may be prepared concurrently with the soil survey. The soundings should be performed at locations that alternate with the borings. Core borings will be performed in the deeper cuts in order to define the character of the rock. The core boring locations should be determined using the results of the geophysical and soil surveys. In addition to recorded data from the boring logs, a geological reconnaissance should be made noting angles of repose, strikes and dips, and obvious indicators of geologic features (rock outcrops). Existing rock cut slopes should also be observed to determine the effects of weather and time. Rock cores may be subjected to a physical test such as strength tests or testing that would indicate the approximate time that a slope might stand under normal freeze-thaw conditions.

306.07 GROUND WATER OBESERVATION WELLS

THIS SECTION IS UNDER DEVELOPMENT. It will include information on types and uses of wells, and when to use wells.

Table 3-1 Guidelines for Minimum Number of Investigation Points and Depths of Investigation

Pavement Subgrade (Cuts and Fills less than 15 feet)	For two (2) lane roads or single lane ramps place one boring every 200 feet, alternating along the centerline of each lane (See Figure 3-6a). For divided highways, one boring should be drilled every 100 ft, alternating between the centerline of each lane sets (See Figure 3-7a).	Each boring should be drilled to at least 5 feet below the proposed subgrade elevation (in cut areas). In fill areas, the borings should be drilled to a depth equal to the height of fill but not less than 5 feet below the existing grade. The boring depths should be extended in areas where deep utilities are to be installed in the vicinity of the proposed pavement area. In this case, the borings should be drilled to the lowest invert elevation of the adjacent utilities. The borings should be extended to fully penetrate any unsuitable natural soils or existing fill and to penetrate at least 5 feet into the underlying suitable natural soils.
Cut Slopes greater than 15 feet or cuts where bedrock is expected to be encountered above planned depth of excavation.	Place one boring at every 200 ft interval along the anticipated limits of cut (top of slope) along with the boring pattern for pavement subgrade as illustrated in Figures 3-6b and 3-7b. In non-pavement areas, borings should be placed at the anticipated top and bottom of the slope at every 200 feet interval of slope length. These borings should be included in order to define the soil profile for use in stability analysis and/or to estimate rock quantities.	Each boring should be drilled at least 10 feet below the minimum elevation of the cut. If rock is present above design grade, the rock should be cored to the full depth of the planned cut. The borings should fully penetrate any unsuitable natural soil or existing fill encountered at the minimum elevation of cut at least 15 feet into the underlying suitable natural soils. A water level observation well should be installed in at least one boring in order to obtain long-term water level readings.
Embankments greater than 15 feet high	Place one boring at every 200 ft interval along the anticipated limits of fill (toe of slope) along with the boring pattern for pavement subgrade as illustrated in Figures 3-6b and 3-7b. In non-pavement areas, place one boring every 200 feet along the centerline of the embankment and along each toe in order to define the soil profile beneath the entire width of the embankment for use in stability and settlement analysis.	Each boring should be drilled to a depth of at least twice the embankment height. Each boring should be extended to fully penetrate any unsuitable natural soils or existing fill. Each boring should penetrate at least 10 feet into the underlying suitable natural soils.
Retaining Walls and Sound Walls	Borings spaced between 100 and 200 feet intervals along the alignment of the wall. For anchored or tieback walls, an additional boring should be sited in the anchored or tieback zone. For soil nail walls, additional borings should be performed behind the wall at a distance corresponding to 1.0 to 1.5 times the height of the wall.	Each boring should extend below the bottom of the wall to a depth of between 1.0 to 2.0 times the wall height or to the depths indicated for shallow or deep foundations. The borings should be extended to fully penetrate any unsuitable soils or existing fill. Each boring should extend at least 10 feet into competent material of suitable bearing capacity. If rock is encountered, it should be cored to a depth of at least 5 feet to determine the integrity and load capacity of the rock, and to verify that the boring was not terminated on a boulder.

Bridge Piers and Abutments on Shallow Foundations	For bridges less than or equal to 100 feet wide, a minimum of one boring should be performed per substructure. For bridges greater than 100 feet wide, two borings should be performed per substructure.	The borings should be drilled to a depth where the stress increase due to estimated footing load is less than 10% of the existing effective overburden stress. Typically, this depth represents approximately 2 times the estimated width of the pier footing, or 4 times the estimated width of the strip footing (L/B > 10). The borings should fully penetrate any unsuitable soils or existing fill and extend at least 10 feet into competent material of suitable bearing capacity. If rock is encountered, it should be cored to a depth of at least 5 feet to determine the integrity and load capacity of the rock, and to verify that the boring was not terminated on a boulder.
Bridge Piers and Abutments on Deep Foundations	For bridges less than or equal to 100 feet wide, a minimum of one boring should be performed per substructure. For bridges greater than 100 feet wide, two borings should be performed per substructure.	In soils, the depth of investigation should extend at least 15 feet below the anticipated pile or shaft tip elevation or a minimum of 2 times the maximum pile group dimension, which ever is greater. For piles bearing on rock, a minimum of 10 feet of rock core shall be obtained at each investigation point in order to determine the integrity and load capacity of the rock, and to verify that the boring was not terminated on a boulder. For drilled shafts that are supported on, or socketed into the rock, obtain a minimum of 10 feet of rock core, or a length of rock core equal to at least 3 times the estimated shaft diameter (for isolated shafts) or 2 times the maximum shaft group dimensions, which ever is greater. The coring shall extend below the anticipated shaft tip elevation to determine the physical and strength characteristics of the rock within the zone of foundation influence.
Stormwater Management Ponds	A minimum of two borings should be drilled per basin less than 2 acres in size. One boring should be drilled in the impoundment area and the other in the area of the proposed dam. One additional boring shall be drilled for each additional acre of pond area greater than two acres. At least one boring should be drilled to evaluate the foundation support for the outfall structure.	Each boring performed within the impoundment area should extend a minimum of 5 feet below the proposed bottom elevation of the proposed basin. The borings for the dam and the outfall structure(s) should be drilled to the depths recommended (above) for embankments and foundations, respectively. The borings should fully penetrate all unsuitable natural soils or existing fill and shall extend at least 5 feet into the underlying natural soils. A water level observation well should be installed in at least one boring in order to monitor the long-term ground water levels.
Pipes and Culverts (greater than or equal to 36 inches in diameter)	One boring should be performed at each end wall and at 200-foot intervals along the length of the pipe or culvert. Foundation investigation is generally not required for pipes and culverts less than 36 inches in diameter.	The borings should be drilled to at least one pipe diameter below the invert elevation of the pipe or culvert. The borings should be extended to fully penetrate any unsuitable natural soils or existing fill and extend at least 5 feet into the underlying natural soils. A water level observation well should be installed in at least one boring to monitor long-term groundwater level in areas where it is expected to be encountered at or above the design invert grade of the pipe or culvert.

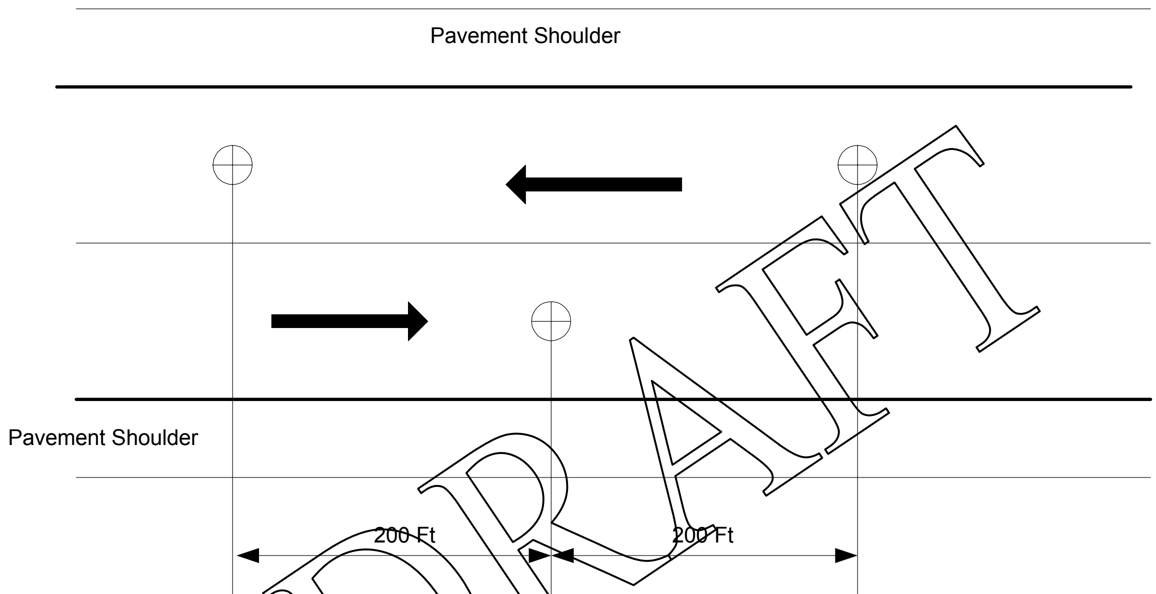

Figure 3-6a   Boring Layout for a Two (2) Lane Road or Single Lane Ramp

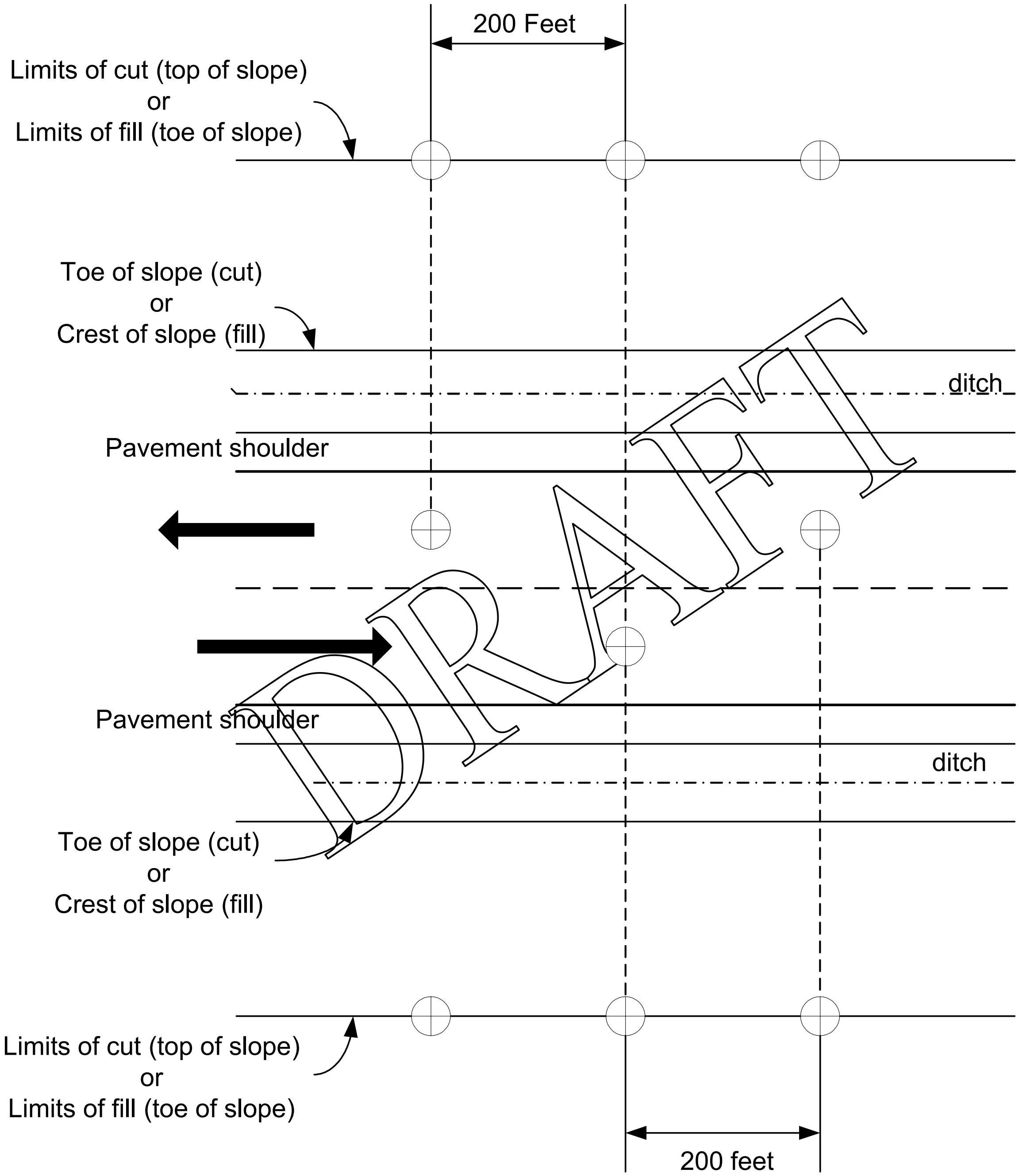

Figure 3-6b Boring Layout for a Two (2) Lane Road with Cut or Fill Slopes Equal to or Greater than 15 ft High or Area Where Rock is Expected to be Encountered above the Planned Depths of Excavation

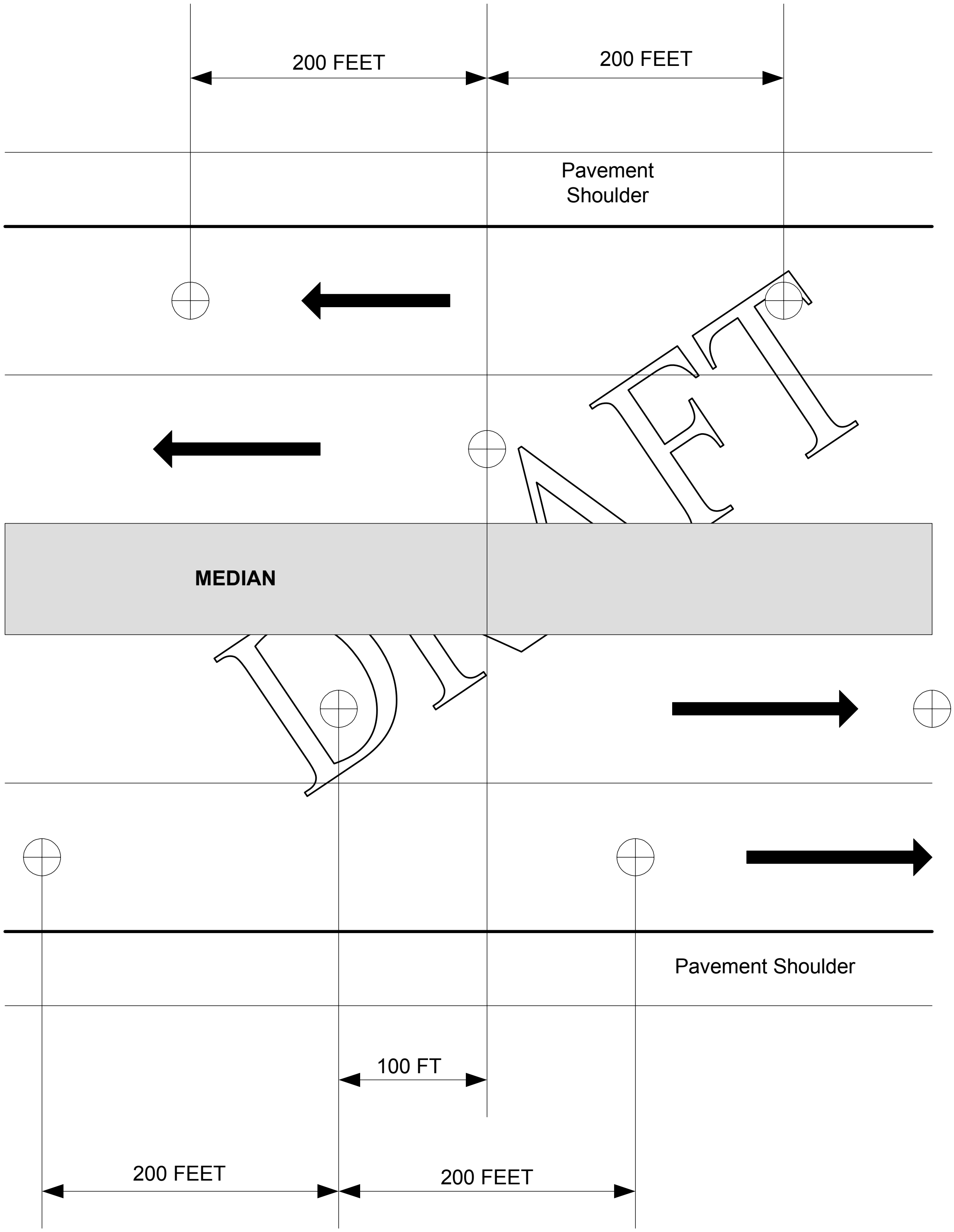

Figure 3-7a Boring Layout for a Four (4) Lane Divided Road

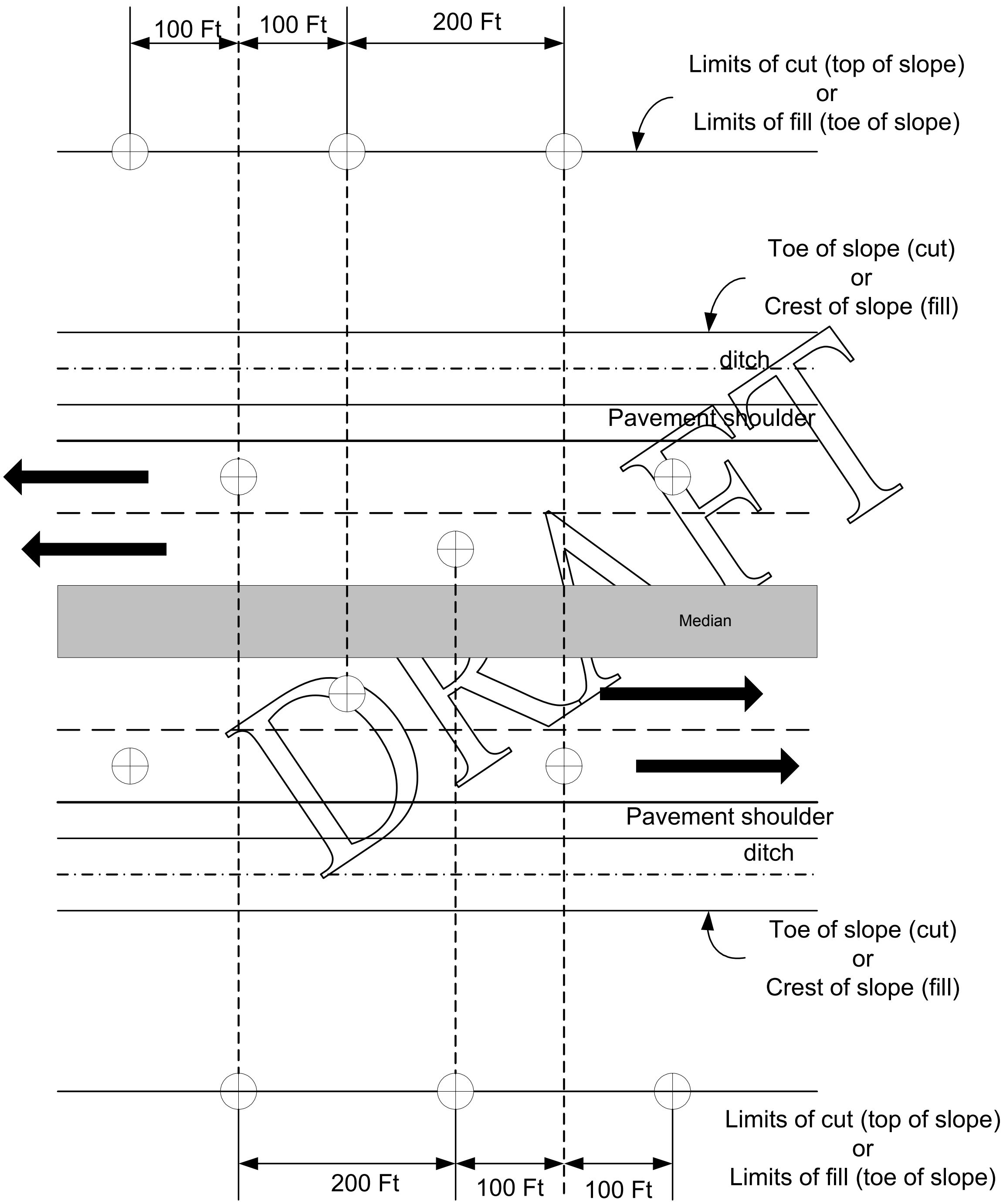

Figure 3-7b Boring Layout for a Four (4) Lane Divided Road with Cut or Fill Slopes Equal to or Greater than 15 ft High or Areas Where Rock Excavation is Expected to be Encountered above the Planned Depths of Excavation

306.08 PAVEMENT CORING PROGRAM

THIS SECTION IS UNDER DEVELOPMENT. It will include a descriptive process related to pavement cores and guidelines for the location, spacing and number of cores for both asphalt and concrete pavement.

306.09 LABORATORY TESTING PROGRAM

The number and type of laboratory tests are generally based on the characteristics of the underlying soils strata, the need for test data relating to the geotechnical analysis and design of the proposed structures, and experience. The laboratory tests should be selected to provide the desired and necessary data as economically as possible. In general, relatively few laboratory tests can provide the data when they are performed on carefully selected representative samples.

Index tests and performance tests are the two basic categories of laboratory tests that should be considered when developing a laboratory testing program. Index tests are performed to obtain general information about the consistency of a soil. Performance tests measure specific soil properties such as shear strength, compressibility and permeability. Table 3-2 provides a summary of the typical soil index tests, and Table 3-3 provides a summary of the typical performance tests that are utilized for design and constructability assessment.

Most engineering soil properties used for design can be estimated with a reasonable degree of accuracy based upon published correlation tables and charts utilizing index tests and/or from in-situ test methods described in Section 309.03 of this Manual. Performance tests provide specific data relating to engineering performance of the soil, but they can be costly and time consuming to perform. In general, performance tests are justified if the data will reduce materials and/or construction costs, and will reduce the risk of a costly failure of a structure. Table 3-4 provides general guidelines for selecting appropriate performance tests that should be performed depending upon the type of structure to be analyzed.

Table 3-2 Methods for Testing the Index Properties of Soils

Methods for index testing of soils.

Test	Procedure	Applicable Soil Types	Applicable Soil Properties	Limitations / Remarks
Moisture Content, w_n	Dry soil in oven at 100 $\pm$ 5 °C	Gravel, sand, silt, clay, peat	e_o, γ	Simple index test for all materials
Unit Weight and Density	Extract a tube sample; measure dimensions and weight;	Soils where undisturbed samples can be taken, i.e., silt, clay, peat	γ_{tot}, γ_{dry}, ρ_{tot}, ρ_{dry}, σ_{vo}	Not appropriate for clean granular materials where undisturbed sampling is not possible. Very useful index test.
Atterberg Limits, LL, PL, PI, SL, LI	LL – Moisture content associated with failure at 25 blows of specimen in Casagrande cup PL – Moisture content associated with crumbling of rolled soil at 3.2 mm	Clays, silts, peat; silty and clayey sands to determine whether SM or SC	Soil classification	Not appropriate in non-plastic granular soil. Recommended for all plastic materials.
Mechanical Sieve	Place air dry material on a series of successively smaller screens of known opening size and vibrate to separate particles of a specific equivalent diameter	Gravel, sand, silt	Soil classification	Not appropriate for clay soils. Useful, particularly in clean and dirty granular materials
Wash Sieve	Flush fine particles through a U.S. No. 200 sieve with water;	Sand, silt, clay	Soil classification	Needed to assess fines content in dirty granular materials
Hydrometer	Allow particles to settle, and measure specific gravity of the solution with time.	Fine sand, silt, clay	Soil classification	Helpful to assess relative quantity of silt and clay
Specific Gravity	The volume of a known mass of soil is compared to the known volume of water in a calibrated pyncnometer	Sand, silt, clay, peat	Used in calculation of e_o	Particularly helpful in cases where unusual solid minerals are encountered
Organic Content	After performing a moisture content test at 110 °C, the sample is ignited in a muffle furnace at 440 °C to measure the ash content.	All soil types where organic matter is suspected to be a concern	Not related to any specific performance parameters, but samples high in organic content will likely have high compressibility	Recommended on all soils suspected to contain organic materials

Symbols used

e_o:	in-situ void ratio	ρ_{tot}:	total density
γ:	unit weight	ρ_{dry}:	dry density
γ_{tot}:	total unit weight	σ_{vo}:	total vertical stress
γ_{dry}:	dry unit weight		

Table 3-3 Methods for Performance Testing of Soils

Methods for performance testing of soils.

Test	Procedure	Applicable Soil Types	Soil Properties	Limitations / Remarks
1-D Oedometer	Incremental loads are applied to a soil specimen confined by a rigid ring; deformation values are recorded with time; loads are typically doubled for each increment and applied for 24 hours each.	Primarily clays and silts; Granular soils can be tested, but typically are not.	σ_p', OCR, C_c, $C_{c\varepsilon}$, C_r, $C_{r\varepsilon}$, C_α, $C_{\alpha\varepsilon}$, c_v, k	Recommended for fine grained soils. Results can be useful index to other critical parameters
Constant rate of Strain Oedometer	Loads are applied such that Δu is between 3 and 30 percent of the applied vertical stress during testing	Clays and silts; Not applicable to free draining granular soils.	σ_p', C_c, $C_{c\varepsilon}$, C_r, $C_{r\varepsilon}$, c_v, k	Requires special testing equipment, but can reduce testing time significantly
Unconfined Compression (UC)	A specimen is placed in a loading apparatus and sheared under axial compression with no confinement.	Clays and silts; cannot be performed on granular soils or fissured and varved materials	$s_{u,UC}$	Provides rapid means to approximate undrained shear strength, but disturbance effects, test rate, and moisture migration will effect results
Unconsolidated Undrained (UU) Triaxial Shear	The specimen is not allowed to consolidate under the confining stress, and the specimen is loaded at a quick enough rate to prevent drainage	Clays and silts	$s_{u,UU}$	Sample must be nearly saturated. Sample disturbance and rate effects will affect measured strength.
Isotropic consolidated drained compression (CIDC)	The specimen is allowed to consolidate under the confining stress, and then is sheared at a rate slow enough to prevent build-up of porewater pressures	Sands, silts, clays	ϕ', c', E	Can be run on clay specimen, but time consuming. Best triaxial test to obtain deformation properties
Isotropic consolidated undrained compression (CIUC)	The specimen is allowed to consolidate under the confining stress with drainage allowed, and then is sheared with no drainage allowed, but porewater pressures measured	Sands, silts, clays, peats	ϕ', c', $s_{u,CIUC}$, E	Recommended to measure pore pressures during test. Useful test to assess effective stress strength parameters. Not for measuring deformation properties
Direct Shear	The specimen is sheared on a forced failure plane at a constant rate, which is a function of the hydraulic conductivity of the specimen	Compacted fill materials; sands, silts, and clays	ϕ', ϕ'_r	Requires assumption of drainage conditions. Relatively easy strength test.
Flexible Wall Permeameter	The specimen is encased in a membrane, consolidated, backpressure saturated, and measurements of flow with time are recorded for a specific gradient	Relatively low permeability materials (k $\leq 1\text{x}10^{-5}$ cm/s); clays & silts	k	Recommended for fine grained materials. Backpressure saturation required. Confining stress needs to be provided. System permeability must be at least an order of magnitude greater than that of the specimen. Time needed to allow inflow and outflow to stabilize.
Rigid Wall Permeameter	The specimen is placed in a rigid wall cell, vertical confinement is applied, and flow measurements are recorded with time under constant head or falling head conditions	Relatively high permeability materials; sands, gravels, and silts	k	Need to control gradient. Not for use in fine grained soils. Monitor for sidewall leakage.

Symbols used

ϕ':	peak effective stress friction angle	OCR:	overconsolidation ratio	$C_{c\varepsilon}$:	modified compression index
ϕ'_r	residual effective stress friction angle	c_v:	vertical coefficient of consolidation	C_r:	recompression index
c':	effective stress cohesion intercept	E:	Young's modulus	$C_{r\varepsilon}$:	modified recompression index
s_u:	undrained shear strength	k:	hydraulic conductivity	C_α:	secondary compression index
σ_p':	preconsolidation stress	C_c:	compression index	$C_{\alpha\varepsilon}$:	modified secondary compression index

Table 3-4 Guidelines for Conducting Performance Tests

Types of Structures	Required Analysis	Performance Tests
Cut slopes greater than 15 feet high and/or slopes steeper than 2H:1V	Stability analysis	Strength tests to include triaxial or unconfined compression testing for fine-grained soils, or direct shear testing for coarse-grained soils
Embankments greater than 10 feet high supported on very soft to soft and highly compressible soils (N<10)	Stability and Settlement Analysis	Strength testing to include triaxial or unconfined compressive strength testing and consolidation testing for fine-grained soils (and for coarse grained soils that contain more than 30% passing the No. 200 sieve
Embankment greater than 30 feet high regardless of the consistency or density of the supporting soils.	Stability and Settlement Analysis	Strength testing to include triaxial or unconfined compressive strength testing and consolidation testing for fine-grained soils (and for coarse grained soils that contain more than 30% passing the No. 200 sieve
Concrete retaining walls, abutments, MSE walls greater than 10 feet high	External stability analysis, bearing capacity, and settlement analysis	Strength testing to include triaxial or unconfined compressive strength tests for the soils beneath and retained behind the structure, and consolidation testing of fine-grained soils that support the structure

SECTION 307 CLASSIFICATION OF SOILS - FIELD AND LAB

307.01 FIELD CLASSIFICATION OF SOILS – SOIL BORING LOGS

Field classification of soils should be performed in general conformance with Unified Soil Classification System per ASTM D-2487 (Classification of Soils for Engineering Purposes) and as noted herein. Both AASHTO and the Federal Highway Administration consider this method acceptable. It is the **STANDARD** that has been adopted by VDOT for all projects. The AASHTO method should **not** be used to classify soils in the field. The approved **standard format** used to describe the various soil strata is shown below. The Geologist/Geotechnical Engineer may expand upon this format by including other terms such as the density and compactness of the soil, geology, etc. that is unique to that project.

307.01 (a) STANDARD FORMAT

(Gradation) (Secondary Component Adj.) (PRIMARY Component Noun) ("with" component) (,) ("trace" component) (,) ("contains" component) (,) (Color) (,) (Moisture) (,) (ASTM Group Symbol) (expanded terms, if needed**)**

307.01 (b) TERMS

PRIMARY Component – The primary soil component constitutes 50% or more (by weight) of the total soil component. The primary soil component should be written in capital letters so it is easily identified in the description. There are four primary material types defined in ASTM D-2487. The primary constituents are: GRAVEL, SAND, CLAY and SILT. These materials are defined by their plasticity and gradation. The soils should be described in accordance with the Group Names included in the flow charts in ASTM D-2487. Other primary soil components are ORGANIC SOIL (OL/OH) and PEAT (PT). Organic soils can exhibit either low or high plasticity. They are generally dark brown or black in color and may have an organic order. The soils may also contain organic matter (roots, wood, etc.), but not in all cases. Peat is composed primarily of vegetative tissue in various stages of decomposition. It has a fibrous texture, a dark brown to black color, and an organic odor. Peat is generally found interbedded within the stratigraphic horizon and should not be confused with organic ground cover such as topsoil and forest litter.

Gradation – Gradation (fine, medium, coarse) is used only when the primary name is a coarse-grained soil (sand or gravel). For sand soils use fine, medium, coarse, or a combination of the three such as fine to medium, fine to coarse, or medium to coarse. For gravels use fine, coarse, and fine to coarse. (For gravel there is no medium size designation according to ASTM).

Secondary Component – The secondary soil component constitutes between 30% - 50% (by weight) of the total soil component. Secondary components are defined as follows: Sandy, Gravelly, Silty or Clayey. (For visual classification purposes, use only one Secondary Name for each classification, such as Clayey SAND or Silty Sand and NOT Clayey Silty SAND).

"**with**" **component** – The soil component that represents between 15% - 30% (by weight) of the total soil component, such as Clayey SAND with gravel or LEAN CLAY with sand and gravel.

"**trace**" **component** – Soil component that represents less than 15% (by weight) of the total soil component, such as POORLY GRADED SAND, trace silt or Sandy FAT CLAY, trace gravel.

"**contains**" **component** – This term pertains to non-ASTM soil materials such as root fragments, mica, shell fragments or organic matter. It should also be used to signify the presence of man-made materials such as crushed stone, brick fragments, concrete, glass, wood fragments, construction debris, etc. If the portion of the foreign matter represents more than 30% (by weight) of the soil component, then include statements such as "contains heavy concentrations of ****", such as Silty SAND, contains heavy concentrations of shell fragments. "Contains" should also be used to identify lenses, layers, or pockets of distinctly different material than the parent soil of the sample. A "layer" is defined as a stratum that is between 1 and 12 inches in thickness, a "lens" is a stratum that is less than 1 inch thick, and "pockets" are materials that are isolated within the total soil matrix. See the examples below:

Fine to coarse Silty SAND, contains fat clay pockets, red brown, moist (SM)
Sandy Lean CLAY, trace gravel, contains sand lenses, tan, wet (CL)
FAT CLAY with sand, contains peat layers, dark gray, wet (CH)

Color – This descriptor is recorded while the soil is in a moist state. For visual classification purposes only, the primary colors need to be identified. The soil may have a single color (red, brown, green, gray, light gray, dark gray, etc.), a combination of colors (red-brown, green-gray, etc.) or multiple colors (such as red-brown, tan and light gray). The use of more than three color descriptors is generally considered unnecessary. The color may also be followed by the term "mottled" if colored areas are blotchy, amorphous, and/or irregularly shaped. Mottling is generally noted as faint gray or brown areas within a stratum or series of strata.

Moisture – This descriptor is recorded at the time of sampling. The soil moisture should be defined as dry, moist or wet. <u>Do not use</u> combinations such as moist to wet or adjectives such as very moist or very wet.

Dry – Absent of moisture, dusty, dry to the touch
Moist – Damp, but no visible water
Wet – Visible free water

The moisture content may not be the same throughout the entire sample. This is especially true if the sample interval spans the contact with the ground water table. In this case, the depth of the change in moisture should be indicated. At the depth where the moisture content changes, use the term "ditto" for the soil description and indicate the change in the moisture condition. For example, a sample was taken between 8 and 10 feet and the ground water table was encountered at 9 feet. The soil was moist above 9 feet and wet below 9 feet and the soil type does not change. The sample should be classified as follows:

Fine to medium Silty SAND, trace gravel, brown , moist (SM)
ditto – wet below 9 feet

ASTM Group Symbols – These symbols should correspond to the Group Name indicated in the flow charts in ASTM D-2487. If the soil consists of fill material, then the group symbol should be followed by a dash and the word FILL, e.g., (SM-FILL).

ditto – for better clarity of the boring log, and for greater ease of classification in the field, the term "ditto" may be used to signify a change in the minor soil components, color and moisture of the same soil. Ditto should not be used where the stratigraphy changes, even if the soil classification is the same. If the term ditto is to identify a discrete change at a particular depth, the partial description should be followed by "at __ feet" or "between __ feet". If the term ditto is to signify a change that is constant with depth, "below _ feet" should follow the partial description. For example:

ditto, contains organic matter at 6 feet
ditto, contains clay layers between 6 feet and 10 feet
ditto, with sand, red and brown below 10 feet

The ditto term should not be used if the change in the minor component of the soil results in a change of the group symbol for the material. This is generally true only for coarse-grained soils. For example, "ditto" should not be used to describe a fine Silty SAND (SM) that changes in silt content to "with" or "trace" of silt since the group symbol according to ASTM changes to (SP-SM) or (SP), respectively.

Ground Cover – The type and depth of ground cover should be identified on the boring log. If the ground is bare, then simply indicate "no ground cover". Ground cover can be organic such as topsoil, root mat, forest litter, etc. In a cultivated field it is important to note cultivation depths, e.g., "Cultivated to a depth of approximately __ feet". Determine the thickness of the organic ground cover by using a shovel. Measuring the thickness of the layer in the SPT sampler generally results in false readings since the sampler has a tendency to compress the material. Ground cover can also consist of man-made structures such as concrete, pavement, crushed stone, etc. Typically, the thickness of these materials can be determined after drilling through the material. In the case of pavement layers, each component of the pavement should be measured and noted on the log.

Fill and Possible Fill – It is essential that man-made (FILL) materials be properly distinguished from soil that formed naturally. These soils typically contain debris or an unusual stratification that identifies them as FILL. If the soil is believed to be fill, but is uniform and free of debris, and it cannot be identified by other means, then the soils may be referred to as POSSIBLE FILL. Fill and Possible Fill soils are classified using the same terminology as for natural soils except the term FILL or POSSIBLE FILL is added to the ASTM Group Symbol. Examples are:

> Fine to medium Clayey SAND, trace gravel, contains brick fragments, red brown, moist (SC – FILL)
> Sandy LEAN CLAY, with gravel, brown, moist (CL – POSSIBLE FILL)

In some cases, the FILL may consist primarily of construction debris or rubble, and not soil. In this case, the classification of the material may be as follows:

> RUBBLE FILL, contains bricks, concrete block, wood, and other construction debris
> TRASH FILL, contains tires, tree stumps, and domestic debris

307.01 (c) OTHER CONSIDERATIONS

Stratification – Delineations are required between soil classifications with different group symbols. Delineations shall also distinguish between changes in the geologic classification, if necessary. Accordingly, the driller should make note on the field log of the depth of each change in material and/or type of material. Unless the contact between two distinct strata is apparent in the sampler, the contact should be assumed to occur halfway between the previous sample and the subsequent sample. For example, if the soil in the upper (previous) sample from 2 to 4 feet classified (SC), and the next (subsequent) sample from 8 to 10 feet classified (CL), then the contact should be shown at 6 feet. If the contact is observed in the sampler, then note the break at the depth observed. A jar sample of each material type should be taken when there is a change in material within the sampler. The contact may also be shown at other depths if the driller observes or perceives the change in contact while advancing the augers. A complete description should be provided for each stratum. The term “ditto” (described above) may be used to identify slight variations within a stratum.

Geology – Knowing the soil’s geologic formation can be a factor in determining the engineering properties of the soils. Before drilling, the Driller and/or Geologist/Geotechnical Engineer should be aware of the general geologic conditions that may exist. Changes in the geology within a particular soil profile should be indicated on the boring log. As an example, it would be appropriate to record the depth at which fine and/or coarse-grained alluvial soils change to fine and/or coarse-grained residual soil. If a particular formation is identifiable, it would be appropriate to note its name, such as the Yorktown Formation.

Ground water – Ground water data should be indicated on **every** boring log. The distance below the existing ground surface to the top of ground water surface should be measured. Record the depth at which it is encountered during drilling, at the completion of the boring, and after the casing (augers) are removed from the borehole. The cave-in depth should also be measured and recorded. If water is not encountered, then the term **“DRY”** should be recorded. If long-term readings are taken (i.e., 24 hour readings) they should be noted on the log. The installation of water level observation wells should also be noted. Record all measurements taken from those wells on the boring logs.

307.02 LABORATORY CLASSIFICATION OF SOILS

Laboratory classification of soils should be performed in accordance with ASTM D 2487-98 (Unified Soil Classification System). This method is considered acceptable by both AASHTO and FHWA and it is the **STANDARD** that has been adopted by VDOT for all projects.

The criteria used to classify soils based on laboratory tests are generally the same as the criteria used for field classification. Field classification of soils is described in Section 307.01 of this Manual. It should be noted that the “trace” and “contains” components (included in the Group Name for samples classified in the field) are not identified in the Group Name shown on the flow charts provided in ASTM D 2487. These two components are not required, except to identify any non-soil components such as shell fragments, mica, wood, etc. These should be noted on the laboratory report if they can influence the laboratory classification. The AASHTO Group Classification Symbol may be included with the ASTM Group Symbol for samples classified in the laboratory based upon the gradation and index properties as determined by laboratory tests results. This is generally desirable when classifying soils that will support pavements.

SECTION 308 FIELD DESCRIPTION OF ROCK

308.01 GENERAL

THIS SECTION IS UNDER DEVELOPMENT. It will include guidelines for describing rock.

308.02 ROCK DESCRIPTION

The Geologist/Geotechnical Engineer should describe the rock types found on the project during the initial stages of the investigation. Descriptions should be uniform throughout the investigation. The descriptions should include whatever qualifying terms are necessary to fully describe the type and condition of the rock.

The following information should be included:

(a) Classification of Rock Type - Igneous, Metamorphic, or Sedimentary

(b) Identification of Rock Name - shale, schist, slate, limestone, granite, dolomite, basalt, etc.

(c) Formation Name

(d) Fracturing – Massive, slightly, moderate, or highly fractured

(e) Joint bedding and Foliation spacing in the rock

(f) Weathering – Fresh, very slight, slight, moderate, moderately sever, sever, very sever, or complete

(e) Relative Hardness

(f) Attitude - Strike and dip of bedding and discontinuities

The crew chief or driller may be the best source of information relating to the drilling characteristics of the rock. The information pertaining to the drilling characteristics should be recorded as it occurs during the coring run to avoid its loss. All data should be recorded chronologically as it is observed. **Under no circumstance should this be put off until after the core is retrieved.**

SECTION 309 FIELD INVESTIGATION METHODS

309.01 SOIL INVESTIGATION METHODS

Soil boring logs will require the following information:

(1) Diameter and description of the casing or auger

(2) Weight of hammer and height of drop for driving casing

(3) Number of blows to drive the casing to each successive foot of elevation

(4) Elevation at the top of each different material penetrated

(5) Elevation at the tip of the sampler at the start of the (each) sampling interval.

(6) Elevation at the tip of the sampler at the end of the (each) sampling interval

(7) Elevation at the bottom of the boring.

(8) Weight of hammer and height of drop to drive the split spoon (SPT) sampler

(9) Number of blows to drive the SPT sampler to each successive six-inches of depth

(10) Type of hammer (automatic, safety, donut, etc.)

(11) Length of sample obtained

(12) Soil shall be described in accordance with Section 306.

309.01 (a) HOLLOW STEM AUGERS

A hollow-stem auger has a tubular center shaft that allows for sampling through the auger(s). The hollow-stem acts as a casing and allows for sampling at the bottom of the borehole. A plug is used to block the end of the tubular shaft to prevent cuttings from migrating upward through the hollow stem. When a sampling depth is reached, the plug is removed to permit Standard Penetration Tests to be performed. In very loose sands and soft clays (below the water table), drilling fluids are often used (and maintained) in order to minimize and mitigate disturbance effects.

309.01 (b) CASED BORINGS

When hollow-flight auger equipment is not used, perform cased borings. After driving the casing, use pumps, drill rods, and bits, to flush the soil from the casing. Casing shall be driven vertically through earth and other materials, including boulders and rock veins. Extend the casing to rock or to such depth below the ground surface, as directed. The casing shall be extra-strong pipe with a nominal inside diameter of 2 1/2 or 4 inches. It shall be driven to the depth at which a sample is to be taken, after which the tubular center shaft shall be cleared out to the bottom of the casing. A sample should always be taken in the first 5 feet, and at 5-foot intervals or at changes in material.

When casing is driven, use clean water to clear the tubular center shaft. The operator, when necessary, will keep a continuous record of the blows per foot required for driving the casing. Record the weight of the hammer used to drive the casing and the height of free fall.

Simultaneous washing and driving of the casing will not be permitted except in the case of difficult driving that requires the use of water. Where such use of water is permitted, record the elevations between which simultaneous washing and driving occurred. In some cases of very difficult driving, and where the characteristics of the soil are suitable, permission may be given to discontinue driving the casing and proceed with auger drilling. Should there be an indication that the sides of the hole are collapsing driving of the casing shall be resumed.

309.01 (c) ORDINARY DRY SAMPLES (STANDARD PENETRATION TEST)

Unless undisturbed dry samples are specifically requested, ordinary dry samples (SPT samples) shall be taken at every change in soil formation, changes in soil constituency, and/or at vertical intervals not exceeding 5 feet. Thinly stratified formations it may be necessary to take continuous samples in order to record the soil profile. Ordinary dry samples shall be taken using a split-barrel sampler. The drive shoe of the sampler shall conform to the specifications in ASTM Standard D1586, Penetration Test and Split Barrel Sampling of Soils. The inside diameter of the sampler shoe shall be 1 3/8 inches, the outside diameter 2 inches, and it shall be of sufficient length to take a continuous 2 foot sample. Do not use any sampler not having a split barrel for the entire length of sampler, not containing a ball valve, and/or having a damaged sampler shoe. Ordinary dry samples shall be obtained by driving the sampler not less than 1 1/2 feet into the material below the bottom of the cleaned casing or the auger head, whichever is applicable. If a sample is not retained, the sampler shall be re-driven. The second sample-driving interval shall be extended an additional foot. If the material is so non-cohesive that the second attempt fails to secure a sample, a trap valve (retainer) should be inserted in the shoe of the sampler and the sampler driven a third time. Should this last procedure fail to secure a sample, obtain a sample of the cuttings, pull the augers (without rotating them) and retrieve a sample from the flights, or use a sand-trap to acquire the sample.

Keep a continuous record of the number of blows required to drive the sampler for each 6-inch of penetration. The Driller and/or Geologist/Geotechnical Engineer should record a description of the sample at each of the sampling intervals in accordance with Section 307.01 of this Manual. Unless otherwise directed, only representative samples shall be preserved in glass jars. To facilitate the determination of the relative resistances of the various strata, the sampler shall always be driven with a 140-pound hammer having a free fall of 30 inches.

Unless otherwise directed, the penetration of the sampler shall be a minimum of 18 inches. A penetration resistance of more than 50 blows for 1 inch of penetration shall be considered sampler refusal.

All ordinary dry samples, immediately upon their removal from the sampler, shall be placed and tightly sealed in clear glass jars with screw caps. The lids shall be tight and shall form an effective moisture barrier. Each sample should be of sufficient size to fill the jar. The sample shall be carefully placed in the jar and shall be in its correct orientation (top of the sample at the lid, bottom of the sample at the bottom of the jar). Each jar shall be clearly and accurately labeled. The label shall show the project number, boring number and sample number, depths between which the sample was taken, and the number of blows per 6-inch sampling interval.

The operator (driller) should keep a sufficient and easily accessed supply of clean glass jars in order to prevent any delay in the work. The operator (driller) shall carefully preserve and deliver the samples as specified in Sec. 308 herein.

For each soil that is significant to the project design and construction, bulk samples shall be taken for laboratory testing and analysis. Bulk samples shall consist of a minimum of 50 pounds of soils and shall be stored in cloth or plastic bags. All samples shall be identified with the project number, boring number, station and offset from the project centerline, and depth below the ground surface.

For soil surveys, sampling shall be conducted in accordance with ASTM Designation D420, Investigating and Sampling Soil and Rock for Engineering Purposes.

309.01 (d) UNDISTURBED DRY SAMPLES

Shelby Tube samples of soft clay, organic silt, and cohesive materials of questionable stability will be required. Sampling of cohesive soils should be in accordance to ASTM D1587, Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes. The objective is to obtain samples that have been subjected to a minimum of disturbance. The condition of the soil(s) in the Shelby Tube should represent, as truly as may be obtained, the actual condition of the soil. Undisturbed dry samples shall be taken as directed. In certain cases continuous samples of this type will be required.

When preparing to take an undisturbed sample, all loose and disturbed material shall be removed from the bottom of the casing. Removal of the disturbed material shall be done in such a manner that the soil immediately below the casing will be as undisturbed as possible. Then the sampler shall be lowered slowly to the bottom of the casing and pressed, by hydraulic action, into the soil. The sampler shall be advanced a distance sufficient to fill it to within 3 or 4 inches of its capacity. When using a piston type sampler, the piston should be set flush with the bottom (cutting edge) of the sampler. Then the sampler shall be lowered carefully to rest on the soil at the bottom of the casing. The rod supporting the piston shall then be clamped to the top of the casing so as to be immovable, after which the sampling tube shall be forced down as previously described. Then, the rod controlling the piston and the rod controlling the sampler shall be locked together at the top and the entire assembly shall be slowly withdrawn from the hole.

After the sampler has achieved the specified depth, allow 10 minutes for the soil to decompress, and then slowly rotate the sampler assembly to shear the soil. The sampler assembly should then be carefully removed from the hole and the sampler should be carefully detached. The length of the retrieved sample shall be measured, noted, and compared with the distance pushed. The face of the sampled material shall be carefully trimmed back from the leading (cutting) edge of the tube. The face of the material shall be perpendicular to the axis of the sampler, and not less than 1/2 inch from the face of the cutting edge. The material that is removed shall be retained as a jar sample. All disturbed material shall be removed from the top (trailing edge) of the tube and the length of the intact sample measured to the nearest ½ inch. Both ends of the tube shall be completely filled with microcrystalline wax (use non-shrinking wax such as bees wax; the use of paraffin is not acceptable) and/or approved packing material. The tubes shall then be closed at both ends using snugly fitting caps. The caps shall be secured with friction tape, after which the ends of the tube shall be dipped in the microcrystalline wax. This will provide an airtight seal. Tubes shall be marked “top” and “bottom” to show the vertical orientation of the sample as it was in place.

Each sample should be handled in such a manner that it will reach the laboratory in as near as possible to the condition it was in when removed from the ground, i.e., without loss of water, or damage by freezing, heating, breakage of containers, or other disturbances.

Shelby tubes must be clearly labeled. Labels shall include the following information: project number, boring number, sample number, and depth between which the sample was taken. Make sure to indicate the top (upper) end of the sample tube. The tubes should be kept in the correct vertical orientation during shipping and storage.

The Geologist/Geotechnical Engineer or the operator (driller) will carefully preserve these samples and deliver them to the testing laboratory as soon as possible. Extreme care must be exercised when handling undisturbed samples. Avoid shock or jarring which may affect the character and the integrity of the material. The samples should be transported and stored in accordance with ASTM D4220.

309.01 (e) SCOUR INVESTIGATION

Samples of the predominant soil types shall be taken at each proposed bridge (water crossing) site. The sample shall be transported to the Central Office Materials Division’s Soil Laboratory for particle size analysis testing. Samples shall be obtained using a split-barrel sampler (used in conjunction with the Standard Penetration Test), or from the auger cuttings, or other appropriate means. If core or auger samples are not obtained at the actual substructure locations, then the samples shall be taken as close as possible to those locations. The results of the test(s) shall be submitted to the District Geologist/Geotechnical Engineer who will forwarded them to the Hydraulics Section of the Central Office Location & Design Division.

Sampling for Scour: Test samples shall be taken from the boreholes. Sample the materials that extend from the streambed elevation downward to a depth of twenty feet below the existing streambed, or to competent, intact bedrock. In the coastal plain region, samples shall be taken to a depth of twenty feet below the existing streambed elevation.

Sample Size: The minimum amount of material for the scour sample should not be less than the amount shown in the following table. However, if there are particles that exceed the sizes shown in the chart below, those particles must be included in the sample. The sample must represent the stratum from which it was taken. The mass of the sample shall be increased in proportion to the percentage of large particles, but the maximum sample size shall not exceed 50 pounds.

NOMINAL SIZE OF LARGEST PARTICLES STANDARD (Alternative)		***APPROXIMATE MINIMUM WEIGHT OF SAMPLE***	
millimeters	***inches***	***kilograms***	***pounds***
9.5	***3/8***	***0.5***	***1***
25	***1***	***2***	***5***
50	***2***	***4***	***9***
75	***3***	***5***	***11***

309.02 ROCK INVESTIGATION METHODS

Rock cores are obtained to gather information on the nature and condition of the bedrock. Knowledge of the characteristics of the rock is important when designing rock cut slopes and structure foundations. This knowledge is also important when performing aggregate studies. A continuous sample of the rock core is the ideal that is seldom attained. Soft and/or broken portions of a formation can be pulverized by the coring bit or eroded by the flush water during the coring operation. Unfortunately, the material that is lost has the greatest significance in determining the overall integrity of the rock mass. Therefore, every effort should be made to observe and record information relating to zones of lost or damaged rock. A careful study of the record, together with a close examination of the portion(s) of the cores recovered, will provide clues as to the nature of the disintegrated material lost.

309.02 (a) ROCK CORING EQUIPMENT

Drilling is to be performed using standard core drilling equipment of the fluid flush, rotary type, having hydraulic feed. The sampler shall consist of a double tube core barrel and a diamond-studded bit capable of producing cores having a minimum diameter of 2 1/8 in. (NX). Split double and triple tube core barrels may be used to enhance recovery, and tungsten carbide coring bits may be satisfactory in soft formations. Wire line equipment is recommended for use in difficult drilling conditions such as highly fractured rock formations. The circulating fluid generally consists of plain water, but drilling mud also may be added to the water to increase its lubricity, density, and viscosity.

309.02 (b) PROCEDURES

General

Determine drilling depth by measuring the "stick-up" of the drill rods. The "stick-up" is the distance from the ground surface (at the boring location) to the bottom of the hydraulic swivel (the top of the drill rods). Measurement tolerance shall be held to a tenth of a foot. The length of the core barrel and bit, as well as the shoulder-to-shoulder length of the drill rods, should be measured individually before they are connected to become an assembly. The length of the assembly, minus the length of the "stick-up", equals the depth of the bit in the hole. As the depth of the hole increases, rods should be added to the assembly. Even though it is usually necessary to have the elevation of the ground surface determined before drilling, it is seldom necessary to record all drilling data by means of both depth and elevation. There will be less opportunity for error if the data are recorded in depths only, the only elevation reference being the ground surface at the top of the hole. The important elevations, such as that of the top of the rock, the water table, etc., can be added when the boring log is finalized. The name of the driller should be shown on the boring log.

Rig Setup

Before beginning a coring operation, the driller should ensure that the drill is mounted on a stable base or platform and that the drill rods are in a vertical position. The drill head should be secure and free from eccentricity. Drill rods should be checked for straightness. All bent rods shall be discarded. The core barrel should be inspected to ensure that the inner barrel is rotating freely, and the bit should be checked for excessive wear.

Drilling in Overburden

When advancing a "fishtail" or roller bit through casing, observe the drilling fluid that flows over the top of the casing. Changes in color indicate changes in material. Subsequent to changes in color and/or density, retrieve samples of the material that is suspended in the fluid. Clay, silt, sand, gravel, and boulder horizons can be determined by drilling with a "fishtail" or roller bit; however, the measurements will not be as accurate as when drive sampling.

Depth measurements should be made in accordance with the instructions in Paragraph 308.02(a) above.

Core Drilling

Before seating the core barrel on the rock, a suitable technique shall be used to break up and clear all foreign material and disintegrated rock from the casing.

The coring bit shall be seated on the rock and advanced a maximum depth of 5 feet. Retrieve the core, labeled it, and store in accordance with ASTM D5079. When drilling into igneous and metamorphic rocks, continue coring until advancing a run 5 feet into solid rock. When drilling into sedimentary rocks, particularly in limestone and dolomite, continue coring until advancing a run of 10 feet into solid rock. The length of the core in limestone and dolomite are generally longer due to the potential of cavities that exist with this rock types. The actual length of coring should be at the discretion of the Geologist/Geotechnical Engineer based on known geologic conditions, quality of the core obtained, and the type of structure the investigation is being performed. If the core bit becomes blocked, the barrel should be cleared before continuing the drilling.

Pay strict attention to the drilling characteristics and the circulation returns. Driller's notes are useful to explain probable reasons for core losses. Core losses most often occur when drilling through weathered or fractured rock, or through alternating hard and soft layers (such as interbedded sandstone and shale). The relative position of material that erodes can be determined if the driller is vigilant and maintains accurate records. For example, thin shale layers that are interbedded with sandstone or limestone, or thin clay seams or gouge layers, are frequently eroded. The only indication of their presence may be a momentary discoloration of the return water accompanied by a period of smoother drilling. If core losses are severe, the percentage of loss can be reduced by retrieving the core barrel each time the bit encounters a new type of material.

Improper drilling techniques can cause core loss. The proper drilling speed, water pressure, drill pressure, etc., must be determined by experimentation. Never make a coring run that is equal to the full length of the core barrel, because certain types of rock have a tendency to "swell" from pressure release or wetting.

Retrieving Core Samples

Use the following procedures when using conventional (non-wire line equipment):

At the completion of a coring run, or when the coring bit becomes blocked, the drilling should be stopped and the drill rods and core barrel should be removed from the hole. Each time a core is retrieved, the drill rods should be stacked and the core barrel emptied. Inspect the core barrel to see that it has been completely cleared of core and check the condition of the bit. Bits often lose their gauge while still retaining a good cutting face. The loss of gauge, and consequent loss of clearance, will increase the probability of core loss. If a new bit is installed in a hole cut using a worn bit, the new bit may have to re-cut the rock. Such occurrences (and the associated wear on the core barrel) can be reduced by using a core barrel having a reaming shell. Experienced operators usually keep several bits available, and they change bits to suit conditions and/or materials.

Before the drilling tools are returned to the hole, the driller or the geologist should fit the broken pieces of core together, measure the amount of core recovered, and determine if any core has been lost. If core has been lost, the driller or the geologist should review the notes on the boring log and examine the core to determine where

and why the loss occurred. The suspected reasons for the core loss should be recorded. Any mechanical breaks should be marked in the field with an "X" directly on the core as well as noted on the coring logs.

309.02 (c) FACTORS AFFECTING RECOVERY OF CORE

General

When an unusual core loss occurs, the driller should attempt to determine the cause and then correct the problem. Frequently this is due to the presence of soft, broken, or unconsolidated layers within a formation of otherwise competent rock. The significance of these weak materials to the overall performance for support of foundations cannot be overemphasized.

When core loss is not a result of weak materials, it is usually caused by improper drilling procedures or equipment malfunction. Some reasons for loss of rock core are:

Drilling Too Fast

Improper rotation speed and/or advancing the core barrel too rapidly.

Water Pressure

If too high, it may erode the core; if too low, it may allow the bit to clog. The driller should monitor the water pressure by observing the pressure gauge.

Rotation of the Inner Core Barrel

Causes the ends of adjacent lengths of core to grind against each other.

Whipping of Drill Rods

Worn guides allow the drill head and rods to wobble. Eccentric movement of the core barrel will result in a decrease in the quality of the core and will cause excessive wear on the core barrel.

Information On Core Losses

By carefully observing the responses and/or reactions of the drilling rig, an alert operator can obtain information about the characteristics and/or condition of the material being drilled, including the depths of contacts, cavities, weak zones, etc. The driller should be constantly on alert to note anything revealed by the action of the rig. These observations/notations may enable him to explain any losses of the cored material(s). The action of the pumps and variations in the color and flow of the return drilling fluid are also indicators of changes in the nature and consistency of the rock. The operator shall inform the Geologist/Geotechnical Engineer of the changes in the subsurface conditions as they occur. He should also record them on the boring log. The geologist/engineer should refer to the driller's notes when examining the core.

Loss of Drill Water

Loss of drilling fluid may indicate the presence of voids, fractured zones, or clay seams, and it is important to record the details of this occurrence. Record the depth at which drilling fluid is lost, the range of depths over which such losses occurred, and the depth at which the fluid flow and/or pressure is regained. Close observation (by the driller) is necessary to locate these points accurately.

309.02 (d) CORE BORING LOGS

Core boring logs, in their final form, will require the following information:

(1) Depth and elevation of the bedrock surface

(2) Type of core barrel and diameter of core

(3) Length of core recovered for each coring run, with percentage of recovery, and RQD (Rock Quality Designation, defined as the aggregate length of all pieces of core that are longer than four inches (in any single core run) divided by the length of the core run, assuming an N-size core)

(4) Depth and elevation of each change in the type of bedrock

(5) Depth and elevation of the bottom of the hole

(6) The bedrock shall be described in accordance with the procedure for classification, as prescribed in Sec. 308.02

309.03 IN-SITU TESTING METHODS

Various in-situ testing methods can be used to measure soil properties and/or behaviors. See Table 3-5 for information on the procedures, soil properties, and limitations of each specific test. The three most commonly used tests on are described below.

309.03 (a) VANE SHEAR TEST

The field vane shear test attempts to directly measure the in-situ undrained shear strength of fine-grained, cohesive soils. Specific details of the test are contained in ASTM D-2573.

The test consists of advancing a four-bladed vane to a desired depth and testing the strength of the soil by measuring its resistance to shearing (the force is applied as torque). The vane is to be rotated at a constant rate. Shearing resistance is mobilized on a cylindrical failure surface corresponding to the top, bottom, and sides of the vane assembly. The preferred vane shape is rectangular, having a four-bladed vane with a height/diameter ratio of two.

It is important to accurately characterize the soil in which the vane shear test is performed. The characterization should include information on the presence of roots, shells, sand lenses, and varves, since these may lead to an over-estimation of the strength of the soil.

309.03 (b) CONE PENETROMETER TEST

Basically, the cone penetrometer test consists of pushing a series of cylindrical rods with a cone at the base into the soil at a constant rate of 2 cm/sec. The cone and the friction sleeve are mounted at the tip of a series of rods that transmit downward force that is applied by the drilling rig. The resistance to the applied load on the cone, and the stress on the friction sleeve are recorded continuously during the penetration. A piezo-cone will record pore pressures, in addition to recording point and friction resistance.

A primary benefit of using a cone penetrometer is the ability to record data for the entire exploration depth. The continuous profiles obtained with the cone penetrometer test provide the engineer with data for the various conditions and materials in the stratigraphy. Through the interpretation of the test results, the engineer can generally identify the soil type, estimate a large number of fundamental soil parameters (undrained shear strength, internal angle of friction, N_1, unit weight, effective overburden stress, permeability, OCR, etc.) and to design shallow and deep foundations. Cone penetrometer data can be produced in gINT and incorporated into roadway plans as full MicroStation sheets.

309.03 (c) FLAT DILATOMETER TEST

A dilatometer consists of pushing a flat steel blade that contains an enclosed expanding cylindrical chamber. The blade is attached to the tip of a series of rods. After reaching the desired test depth, a circular steel membrane (that is located on one side of the blade and which covers the cylindrical chamber) is forced outward (horizontally) into the soil. The pressure is recorded at three specific moments during the test. The blade is then advanced to the next testing depth.

Applications for which the dilatometer is ideally suited include: investigations for deep foundations under horizontal and vertical load, shallow foundations under vertical load, and compaction control.

Table 3-5 In-Situ Testing Methods for Soils

In-situ testing methods used in soil.

Method	Procedure	Applicable Soil Types	Applicable Soil Properties	Limitations / Remarks
Electric Cone Penetrometer (CPT)	A cylindrical probe is hydraulically pushed vertically through the soil measuring the resistance at the conical tip of the probe and along the steel shaft; measurements typically recorded at 2 to 5 cm intervals	Silts, sands, clays, and peat	Estimation of soil type and detailed stratigraphy Sand: ϕ', D_r, σ_{ho}' Clay: s_u, σ_p'	No soil sample is obtained; The probe may become damaged if testing in gravelly soils is attempted; Test results not particularly good for estimating deformation characteristics
Piezocone Penetrometer (CPTu)	Same as CPT; additionally, penetration porewater pressures are measured using a transducer and porous filter element	Silts, sands, clays, and peat	Same as CPT, with additionally: Sand: u_o / water table elevation Clay: σ_p', c_h, k_h OCR	If the filter element and ports are not completely saturated, the pore pressure response may be misleading; Compression and wear of a mid-face (u_1) element will effect readings; Test results not particularly good for estimating deformation characteristics
Seismic CPTu (SCPTu)	Same as CPTu; additionally, shear waves generated at the surface are recorded by a geophone at 1-m intervals throughout the profile for calculation of shear wave velocity	Silts, sands, clays, and peat	Same as CPTu, with additionally: V_s, G_{max}, E_{max}, ρ_{tot}, e_o	First arrival times should be used for calculation of shear wave velocity; If first crossover times are used, the error in shear wave velocity will increase with depth
Flat Plate Dilatometer (DMT)	A flat plate is hydraulically pushed or driven through the soil to a desired depth; at approximately 20 to 30 cm intervals, the pressure required to expand a thin membrane is recorded; Two to three measurements are typically recorded at each depth.	Silts, sands, clays, and peat	Estimation of soil type and stratigraphy Total unit weight Sand: ϕ', E, D_r, m_v Clays: σ_p', K_o, s_u, m_v, E, c_h, k_h	Membranes may become deformed if overinflated; Deformed membranes will not provide accurate readings; Leaks in tubing or connections will lead to high readings; Good test for estimating deformation characteristics at small strains
Pre-bored Pressuremeter (PMT)	A borehole is drilled and the bottom is carefully prepared for insertion of the equipment; The pressure required to expand the cylindrical membrane to a certain volume or radial strain is recorded	Clays, silts, and peat; marginal response in some sands and gravels	E, G, m_v, s_u	Preparation of the borehole most important step to obtain good results; Good test for calculation of lateral deformation characteristics
Full Displacement Pressuremeter (PMT)	A cylindrical probe with a pressuremeter attached behind a conical tip is hydraulically pushed through the soil and paused at select intervals for testing; The pressure required to expand the cylindrical membrane to a certain volume or radial strain is recorded	Clays, silts, and peat in sands	E, G, m_v, s_u	Disturbance during advancement of the probe will lead to stiffer initial modulus and mask liftoff pressure (p_o); Good test for calculation of lateral deformation characteristics

. In-situ testing methods (continued).

Method	Procedure	Applicable Soil Types	Applicable Soil Properties	Limitations / Remarks
Vane Shear Test (VST)	A 4 blade vane is slowly rotated while the torque required to rotate the vane is recorded for calculation of peak undrained shear strength; The vane is rapidly rotated for 10 turns, and the torque required to fail the soil is recorded for calculation of remolded undrained shear strength	Clays, Some silts and peats if undrained conditions can be assumed; not for use in granular soils	s_u, S_t, σ_p'.	Disturbance may occur in soft sensitive clays, reducing measured shear strength; Partial drainage may occur in fissured clays and silty materials, leading to errors in calculated strength; Rod friction needs to be accounted for in calculation of strength; Vane diameter and torque wrench capacity need to be properly sized for adequate measurements in various clay deposits

Symbols used

ϕ': effective stress friction angle
D_r: relative density
σ_{ho}': in-situ horizontal effective stress
s_u: undrained shear strength
σ_p': preconsolidation stress
c_h: horizontal coefficient of consolidation
k_h: horizontal hydraulic conductivity
OCR: overconsolidation ratio
V_s: shear wave velocity
G_{max}: small-strain shear modulus
G: shear modulus
E_{max}: small-strain Young's modulus
E: Young's modulus
ρ_{tot}: total density
e_o: in-situ void ratio
m_v: volumetric compressibility coefficient
K_o: coefficient of at-rest earth pressure
S_t: sensitivity